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AIRCRAFT WINDSHIELD BIRD IMPACT MATH MODEL. PART 2. USER'S MANU--ETC(U)

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PART 2

AIRCRAFT WINDSHIELD BIRD IMPACT MATH MODEL
PART 2 - USER'S MANUAL

GORDON R. EIDE

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DECEMBER 1977

TECHNICAL REPORT AFFDL-TR-77-99

Final Report For Period July 1975-December 1977

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AIR FORCE FLIGHT DYNAMICS LABORATORY
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This technical report has been reviewed and is approved for publication.

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		Laminate	Windshield

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Instructions are given for the use of the Bird Impact Math Model Computer Program (IMPACT). IMPACT calculates the transient dynamic response of a finite element model of a windshield system subjected to bird impact. Modeling, input, program functions and output are explained from a user's standpoint.

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FOREWORD

This report is one of a series of reports that describe work performed by Douglas Aircraft Company, McDonnell Douglas Corporation, 3855 Lakewood Boulevard, Long Beach, California 90846, under the Windshield Technology Demonstrator Program. This work was sponsored by the U. S. Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, under Contract F33615-75-C-3105, Project 2202/0201.

This report is divided into three parts. Part 1 is entitled "Theory and Application", Part 2 is entitled "User's Manual", and Part 3 is entitled "Programming Manual." The principal investigators and authors were P. H. Denke for Part 1, G. R. Eide for Part 2, and R. C. Morris for Part 3.

Mr. D. C. Chapin, Capt., USAF Ret., was the Air Force Project Manager during the conceptual phase of the work reported herein. Lieutenant L. G. Moosman (AFFDL/FEW) succeeded Mr. Chapin during the conduct of the program.

Mr. J. H. Lawrence Jr., was the Program Director for the Douglas Aircraft Company.

This report was submitted to the Air Force on 7 December 1977, and covers the work performed during the period July 1975 through December 1977.

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A	Cross-sectional area or point on Ramberg-Osgood stress, strain curve
A_s	Surface area
a_i	Polynomial coefficients ($i = 0, 1, 2, \ldots$)
$\vec{b}$	Bird path unit vector
b_x, b_y, b_z	X, Y, Z components of $\vec{b}$
CON	Constraint number
DIR	Direction number
D_β	Distance traveled by impact footprint in time t_0 to $t_{\beta-1}$
$\vec{d}$	Footprint path unit vector
d_x, d_y, d_z	X, Y, Z components of $\vec{d}$
E	Young's modulus
E_A	Secant modulus at Point A
$\bar{E}$	Tangent to Ramberg-Osgood curve at origin
e	Elongation at rupture
$\bar{F}$	Lumped element forces
F_{avg}	Average impact force
F_β	Resultant impact force for β^{th} increment
F_{ty}, F_{tu}	Allowable stresses for metals
f_β	Impact force, time load distribution factor for β^{th} increment
h	Damping to stiffness ratio
I_L, I_V	Lateral and vertical bending moments of inertia
J	Mechanical equivalent of heat
JT	Joint number

LIST OF SYMBOLS (continued)

$j_{i\beta}$	Joint numbers within impact footprint
L	Effective bird length or laminate number
ℓ	Layer number
ℓ_x, ℓ_y, ℓ_z	X,Y,Z components of a direction vector
M, M_ℓ	Material number
M_p	Point mass
m	Mass of bird
NC	Number of computed polynomial coefficients
NI	Number of input polynomial coefficients
n	Exponent in Ramberg-Osgood equation.
$\vec{n}$	Unit normal vector
n_x, n_y, n_z	X,Y,Z components of $\vec{n}$
n_E	Number of edge degrees of freedom
n_{EL}	Total number of elements
n_e	Number of elements excluding point mass
$n_{\bar{F}}$	Number of lumped element forces
n_{PF}	Total number of element forces
n_G	Number of transformation modes
n_{I_β}	Number of time increments during impact
n_J	Number of joints
n_S	Number of element stresses or strains
n_T	Total number of degrees of freedom
n_{TJ}	Total number of joint degrees of freedom
n_u	Number of unconstrained degrees of freedom

LIST OF SYMBOLS (continued)

n_β	Number of increments in solution
P	Material property number
p,q,r,s	Joint numbers for element definition
s	Specific heat
T_B	Base temperature
T_J	Joint temperature
T_i, V_i	Temperature, property value pairs
t, t_ℓ	Thickness
t_o	Surface offset
t_d	Impact duration time
t_β	Time at end of β^{th} increment
v	Velocity of bird
w	Width
X,Y,Z	Right hand Cartesian coordinates
X_o,Y_o,Z_o	Coordinates of impact point
α_T	Coefficient of thermal expansion
β	Time increment number
ΔE_ℓ	Element numbering increment
ΔJ_ℓ	Joint numbering increment
ζ_{pq}	Stress orientation angle
θ	Angle of impact
ν	Poissons ratio
ρ	Mass density
σ	Axial stress

LIST OF SYMBOLS (continued)

$\bar{\sigma}$, $\bar{\varepsilon}$	True stress, strain
$\bar{\sigma}_A$, $\bar{\varepsilon}_A$	True stress, strain at Point A
$\bar{\sigma}_L$, $\bar{\varepsilon}_L$	True stress, strain at elastic limit
$\bar{\sigma}_r$, $\bar{\varepsilon}_r$	True stress, strain at rupture
τ	Shear stress
ϕ_β	Matrix of impact joint loads
$\delta\phi_\beta$	Matrix of incremental impact joint loads

SECTION I
INTRODUCTION

In recent years design verification of aircraft windshield systems subjected to bird impact has been accomplished primarily by test. A reliable analysis tool is needed to support the design process and reduce the amount of testing required to substantiate the design. This document gives detailed instruction in the use of such a tool--the Bird Impact Math Model Computer Program (IMPACT).

PROGRAM FUNCTION

IMPACT is a CDC oriented computer program for calculating the transient dynamic response of a windshield system to loads resulting from bird impact. The theoretical development and applications, and the program documentation and implementation procedure are found in Parts 1 and 3 (separate volumes) of this report. Appendix A contains specific operational information in the form of direct duplication of Sections II and III of Part 3--Programming Manual. These sections are oriented to the Wright Patterson Computing Facility and should be directly applicable for users at that location. Refer to Part 3--Programming Manual for additional information on implementation and execution at other installations.

PROGRAM CAPABILITIES

IMPACT solves the equations of motion of a finite element representation of the windshield system which can include multi-layered transparencies. In fact, the analysis capability is not limited to windshield systems but may be applied to a finite element model of any structure.

Pre-processing features include the capability to generate joint coordinates and element definition data for a multi-layered, variable thickness transparency from input data defining the surface of the transparency. Also included is the capability to generate model joint loads representing the bird impact by inputting the bird mass and velocity together with model geometry and impact location data. In addition to generated impact loads, the user may independently input other joint loads which may or may not vary

with time. Optionally, the preprocessing features may be by-passed, and the required card input may be provided by the user.

The presence of initial thermal gradients in the structure may be accounted for by inputting temperatures at the joint locations in the finite element model. Not only are thermal deformations accounted for, but also the material properties are calculated as a function of temperature on an element by element basis. The linear version of the program accounts for thermal deformations in the solution. However, in the current version of the nonlinear program, the code which incorporates thermal deformations has been deactivated.

Modal transformation of the equation of motion is used to reduce the problem size to a practical limit, so that a stepwise solution in time may be generated involving a large number of time increments. Either a linear or nonlinear solution of the incremental response may be chosen by the user. The linear solution is based on linear small deflection theory and is applicable to those problems which are expected to respond in a linear fashion. Since it is more economical than the nonlinear solution, it can be advantageous to use the linear solution to perform comparative design studies of a nonlinear system followed by a final nonlinear solution of the chosen design.

The nonlinear solution features an iterative solution within each time increment using the fictitious force approach to account for geometric nonlinearity with updating of joint coordinates and the calculation of an imbalance correction to the applied loads before proceeding to the next time increment. Current experience indicates that the type and number of modes used in the modal transformation may be very significant in nonlinear analysis. Therefore, for accurate results, care and understanding must be exercised in the use of transformation modes. Experience has also shown that nonlinear results are very accurate for both high and low damped systems which are small enough to be analyzed without modal transformation. The nonlinear solution is designed to account for geometric nonlinearity, including large deflections, and material nonlinearity. However, all aspects of the material nonlinearity capability are not complete, so that feature is currently not available.

Both the linear and nonlinear solutions output a file of data containing the modal incremental displacements, accumulated displacements, velocities and accelerations together with element forces, stresses (including the Prandtl-Reuss equivalent stresses) and strains for each time point. This file is generated on magnetic tape. Post-processor capability allows the user to selectively print the modal response data, untransformed displacements, joint coordinates, and element forces, stresses and strains.

The linear or nonlinear static response of a system can also be calculated if the solution is continued until the incremental response becomes insignificant. Static equilibrium is reached in the shortest time if arbitrarily high damping is introduced.

UNITS

The IMPACT program has been developed without dependence on units. The user may choose any system of units he wishes, and he must then be consistent in the use of those units for all data input to the program. Results must be interpreted by the same units used for the input.

PROJECTED IMPROVEMENTS

The following improvements are considered to be important in the further development of IMPACT:

1) Improved impact load generation including pressure distribution within the footprint and the effects of bird and compliant target interaction.

2) Automated mode extraction tailored to nonlinear requirements.

3) Completion of the material nonlinearity capability.

4) Addition of multi-connect capability.

5) Improved postprocessor capability including interactive and/or batch mode plot capability.

6) Improved user convenience.

7) Addition of restart capability.

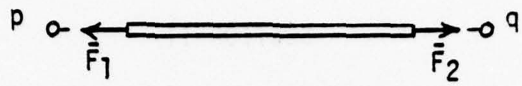
SECTION II

MODELLING CONSIDERATIONS

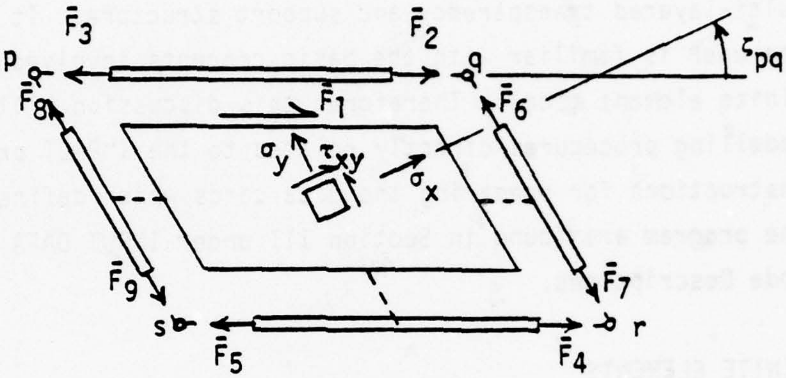
This section contains information needed by the user to create a finite element model of a windshield system which may include a multi-layered transparency and support structure. It is assumed that the user is familiar with the basic concepts involved in creating a finite element model. Therefore, this discussion will be limited to modelling procedures directly related to the IMPACT program. Instructions for preparing the data cards which define the model to the program are found in Section III under INPUT DATA REQUIREMENTS, Data Code Descriptions.

FINITE ELEMENTS

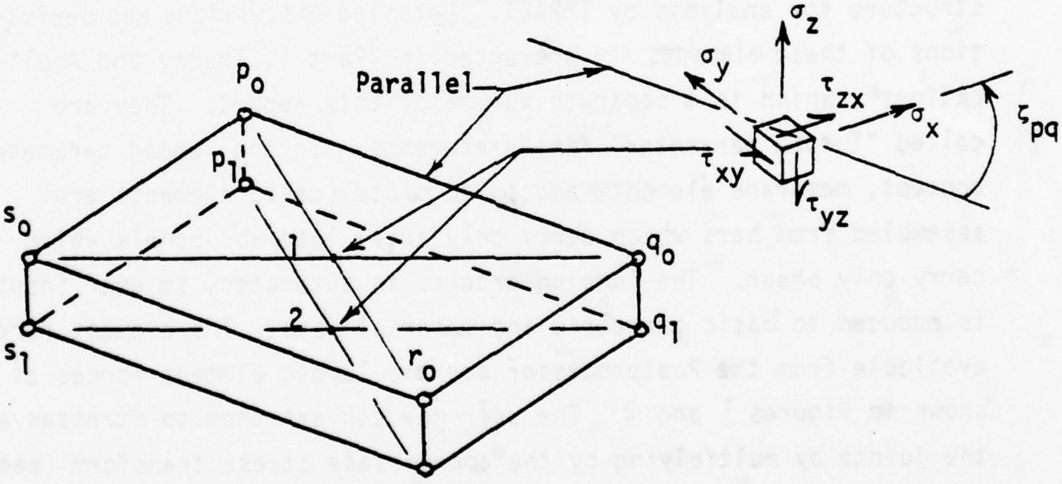
Figure 1 shows the finite elements which may be used to model a structure for analysis by IMPACT. Detailed discussions and derivations of these elements are presented in "Part 1, Theory and Applications", which is a separate volume of this report. They are called "lumped parameter" finite elements. In the lumped parameter concept, membrane elements and solid plate (cell) elements are assembled from bars which carry only axial load and panels which carry only shear. The lumping process is automated, so user input is reduced to basic geometric and material data. The element forces available from the Postprocessor are the lumped element forces as shown in Figures 1 and 2. The user may convert them to stresses at the joints by multiplying by the appropriate stress transform (see Part 1 Appendix C on Element Derivations). They can also be resolved to forces and moments at the mid-plane of a plate element. Element stresses and strains calculated by the program and printed by the Postprocessor are average values at element mid points.



Axial Bar Element



Membrane Element



Cell Element

Figure 1. Finite Elements.

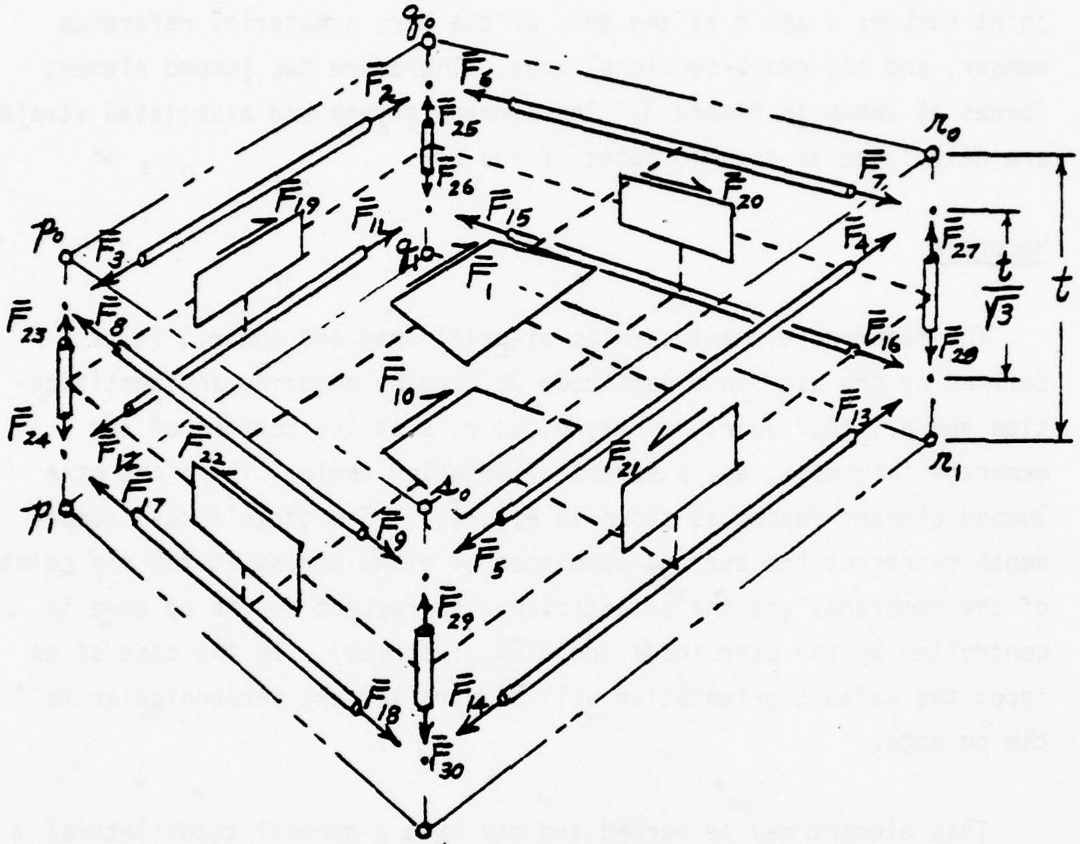


Figure 2. Cell Lumped Element Forces.

Axial Bar

The bar element carries axial load only. It is defined by the user on a data code 20 card by entering an identification number, two joint numbers p and q at the ends of the bar, a material reference number, and the cross-sectional area. There are two lumped element forces as shown in Figure 1. The average stress and associated strain are calculated at the mid point of the bar.

Membrane

The membrane element carries bi-axial load and shear. It is defined by the user on a data code 30 card by entering an identification number, four joint numbers p, q, r, s at the corners of the membrane thickness, and a stress orientation angle. There are nine lumped element forces as shown in Figure 1. The three stress components represent the average condition of plane stress at the mid point of the membrane, and the orientation with respect to the pq edge is controlled by the user input angle ζpq (degrees). In the case of no input the default orientation will be parallel and perpendicular to the pq edge.

This element may be warped and may have a general quadrilateral shape, but accuracy will be best if it is a parallelogram. Bi-axial Poisson coupling is accounted for.

Cell

The cell element carries all types of load. It is defined by the user on a data code 40 card by entering an identification number, eight joint numbers p_0, q_0, r_0, s_0, p_1, q_1, r_1, s_1 at the corners of the cell, a material reference number, and a stress orientation angle,

See Figure 1. It is used to represent a solid hexahedron which should be an approximate parallelepiped for best accuracy. It is called a cell because the lumped parameter representation is a cell composed of 12 bars and 6 shear panels. It is basically a plate element where the joints p_0 through s_0 are in the upper surface of the plate and the joints p_1 through s_1 are in the lower surface. The plate may be thick or thin - joint coordinates place the joints in the true plate surfaces thereby defining the thicknesses at the four corners. Thus, a laminated transparency may be modelled realistically by a stack of cell elements each having the true thickness and properties of the layer it represents.

If a string of cell elements is used to model a beam having a cross-sectional area of A and vertical and lateral bending moments of inertia of I_V and I_L, then the width w and thickness t of the cell elements in the model may be calculated from

$$w = \left(\frac{16\ I_L^3}{3\ I_V}\right)^{1/8} \tag{1}$$

$$t = \left(\frac{432\ I_V^3}{I_L}\right)^{1/8} \tag{2}$$

Such a beam model will have the correct bending stiffnesses both vertically and laterally, but axial stiffness will be sacrificed. If axial stiffness is more important than lateral bending, the following equations may be used to satisfy vertical bending and axial stiffnesses.

$$t = \left(\frac{12\ I_V}{A} \right)^{1/2} \tag{3}$$

$$w = \left(\frac{A^3}{12\ I_V} \right)^{1/2} \tag{4}$$

The six stress components shown in Figure 1 represent the average state of stress at the mid-points of the upper and lower surfaces. Therefore, twelve average stresses and strains are calculated for a cell element. The x and y components are in the plane of the surface, and the x component is oriented with respect to the p_0q_0 edge by the user input angle ζpq (degrees). Figure 2 shows the lumped element forces for a cell element. The lumped elements are located at a reduced depth of $t/\sqrt{3}$ in order to produce the correct bending stiffness. Tri-axial Poisson coupling is accounted for.

Point Mass

A fourth element not shown in Figure 1 is described here. The point mass element represents a local mass attached to the model at a specified joint. It is defined by the user on a data code 50 card by entering an identification number, the joint number where the mass is located, and its contributions in the global X,Y,Z degrees of freedom. These contributions are added to the appropriate diagonal elements of the structural mass matrix. This element is provided for the purpose of including non-structural mass in the finite element model.

GRID DETAIL AND GEOMETRY

Model development usually begins with a drawing or sketch of the structure on which the user lays out a grid representing subdivision of the structure into finite elements. Surface grids and cross-sectional grids define the three dimensional model. Scale drawings are helpful for visualizing finite element shapes and for designing the grid so that important structural features are retained while varying the grid spacing so that model detail is provided in critical regions of the structure. Intersections of grid lines are called joints, and model geometry is defined in terms of joint coordinates.

Generation of joint coordinates is probably the most difficult and time consuming task in creating a finite element model of a complex structure. Some joints may be located exactly at control points for which coordinates are available on a drawing. Sometimes joint coordinates may be scaled from drawings. Coordinates for joints in the surface of a structure are usually calculated from loft data while interior joints are located by offset from the lofted surface. Some coordinates have to be calculated from equations that satisfy section property requirements in local structural elements. Some installations may have interactive graphics or other computer aided techniques to help the user in this process.

Transparency

In a windshield system the transparency may be a single layer or a multi-layered laminate. In either case the user has to lay out the grid and calculate the joint coordinates for the outer surface only. He may then use the Laminate Generator program to generate interior joint coordinates. See Section III under INPUT PREPROCESSING, Laminate Generator. The grid mesh should be fine enough so that the dynamic response

of the structure can be adequately represented. Because of model size limitations (1200 joints) and if there are many layers in a laminated transparency, it is sometimes difficult to provide the desired degree of detail. Compromise may be necessary in the form of coarser grid in areas remote from the impact point, although careful consideration should be given as to whether critical response might occur at locations other than the impact point. Model size can also be decreased by taking advantage of structural symmetry and by modelling less of the support structure. The transparency will have some joints in common with the support structure. Therefore, planning of the transparency grid must be coordinated with important features of the support structure.

Support Structure

As stated above, the grid layout for the support structure is established in coordination with that of the transparency. The extent and degree of detail to be included in the model depends on considerations of factors such as model size limitations and location of impact point. Impact on or near the transparency support members would require more modelling detail to be concentrated in the support members than impact in the center of the transparency.

Extruded, formed or built-up framing members around the transparency are usually modelled as beams composed of cell elements. Load paths connecting the framing members to surrounding shell structure and a portion of the shell structure itself may be realistically represented by bar, membrane and cell elements. Joint coordinates are calculated from loft data and from drawing information.

Loads

Loads are applied to the model at the joints in the global X, Y, Z degrees of freedom. The calculation of bird impact loads at specified joints is described under "Loads Generator". They are introduced in the input stream and converted to transformed loads as described under "MODAL TRANSFORMATION".

ATTACHMENTS

In the overall model, the attachments between the transparency and the support structure must be simplified. A single shear bolted attachment may be represented as a simply supported or hinged connection along a single line of common joints such as joints 16, 39 and 62 in Figure 11. A double shear attachment could be represented by adding membrane elements to connect edge 13, 36, 59 to edge 22, 45, 68. In a laminate having structural plies separated by softer interlayer material the presence of bushings and bolts through the layers can be represented by specifying stiffer shear properties for the interlayer elements along the edges of the laminate. The user can approximate the stiffer properties by hand analysis.

If necessary the user can perform a more detailed study of laminate-bolt-support structure interactions by making a finite element model of the local attachment region. Important features such as bolt, bushing, and portions of the laminate and support structure can then be individually modelled in much more detail than in the overall model of the system. Response of this localized attachment model to typical impact loads can be studied to improve understanding of the interactions of the component parts and to gain insights in how to represent them realistically in the larger model.

CONSTRAINTS

A joint may be constrained (fixed) against displacement in one, two or three specified directions. Constraint in one direction still allows the joint to be displaced in a plane normal to the specified direction. Constraint in two directions fixes the joint against movement in the plane containing the two specified direction vectors but still allows the joint to be displaced normal to the plane. Constraint in three directions fixes the joint in space and allows no displacement in any direction. Constraint data is input on data code 5 cards.

Constraints are used to support the finite element model in a stable manner and to approximate boundary conditions at the edges of the model where structural continuity needs to be represented. For example, on a symmetrically loaded structure the correct boundary conditions at an edge which lies in a plane of structural symmetry are provided by constraining all joints in the plane of symmetry in the degree of freedom normal to the plane. Constraints decrease the problem size, since each constraint eliminates one degree of freedom.

MODEL DIAGRAMS

The user should prepare diagrams of the finite element model showing grid lay-outs and numbering sequences of joints and elements. If a computer aided drawing or plotting capability is available and can be interfaced to read model definition data (or even to help create it), then scale drawings may be produced showing the model from advantageous angles. Often non-scale diagrams are also used to clarify model details. Figures 3 through 8 are example diagrams of a large model having 910 joints, 28 bars, 143 membranes, 460 cells and 4999 degrees of freedom.

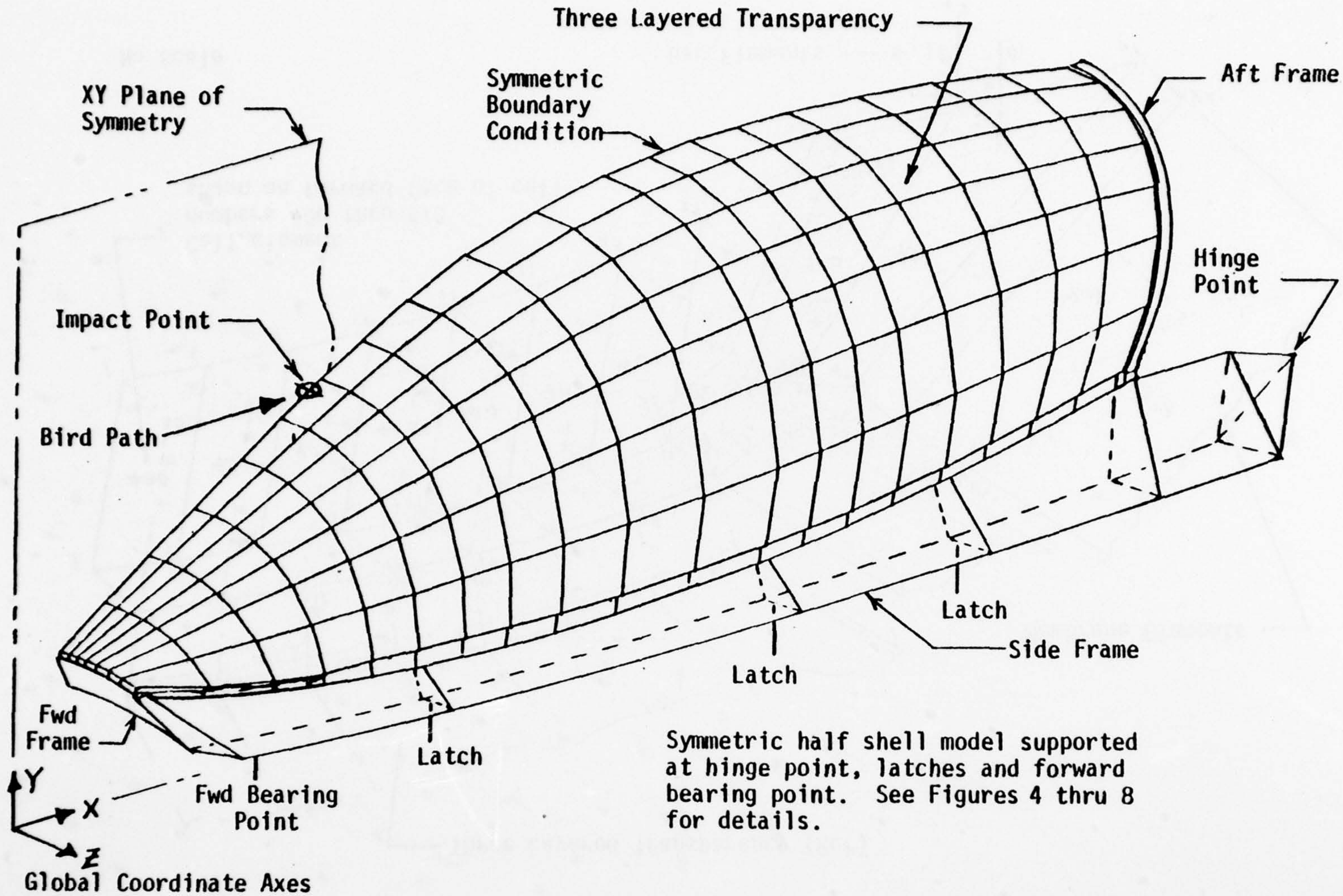


Figure 3. Finite Element Model Diagram, General View.

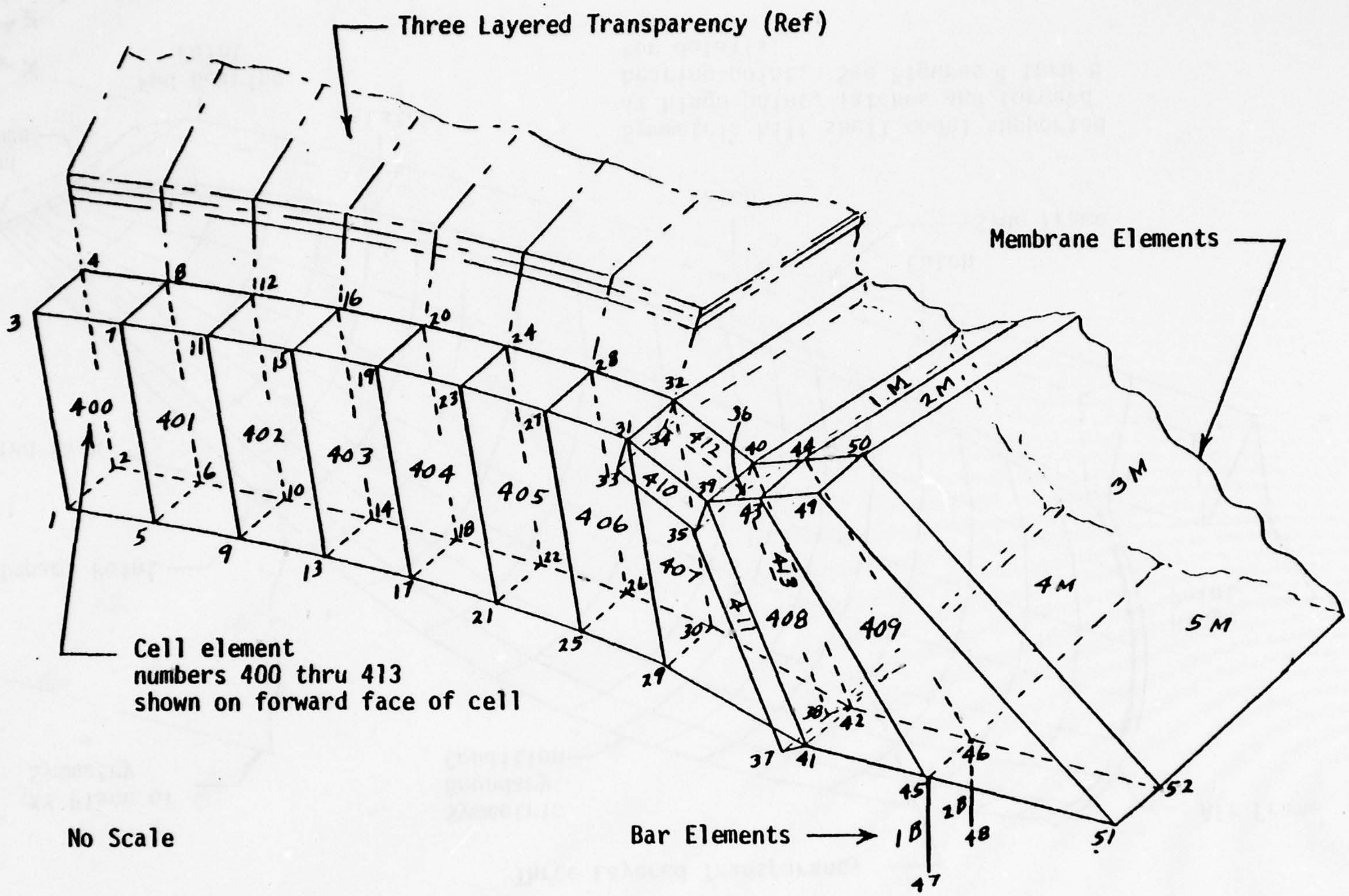
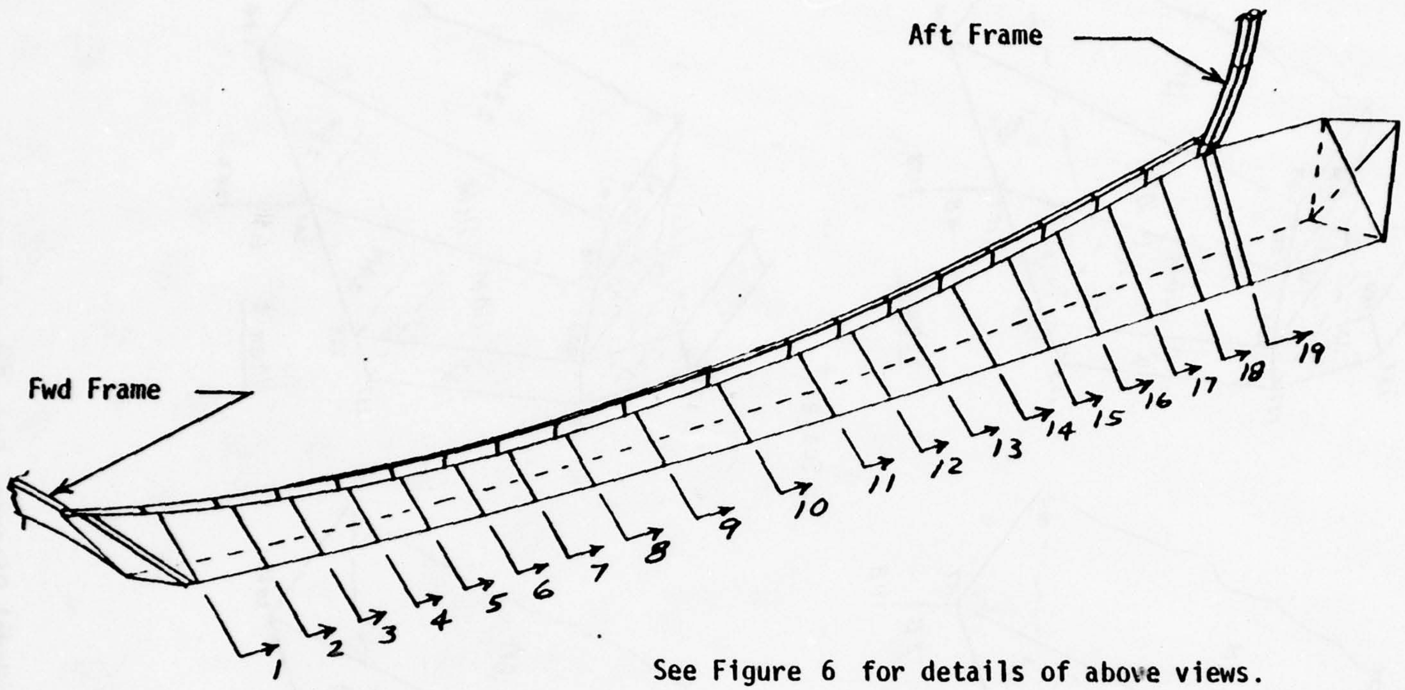


Figure 4. Model Diagram, Forward Frame.



See Figure 6 for details of above views.

Figure 5. Model Diagram, Side Frame Section Cuts.

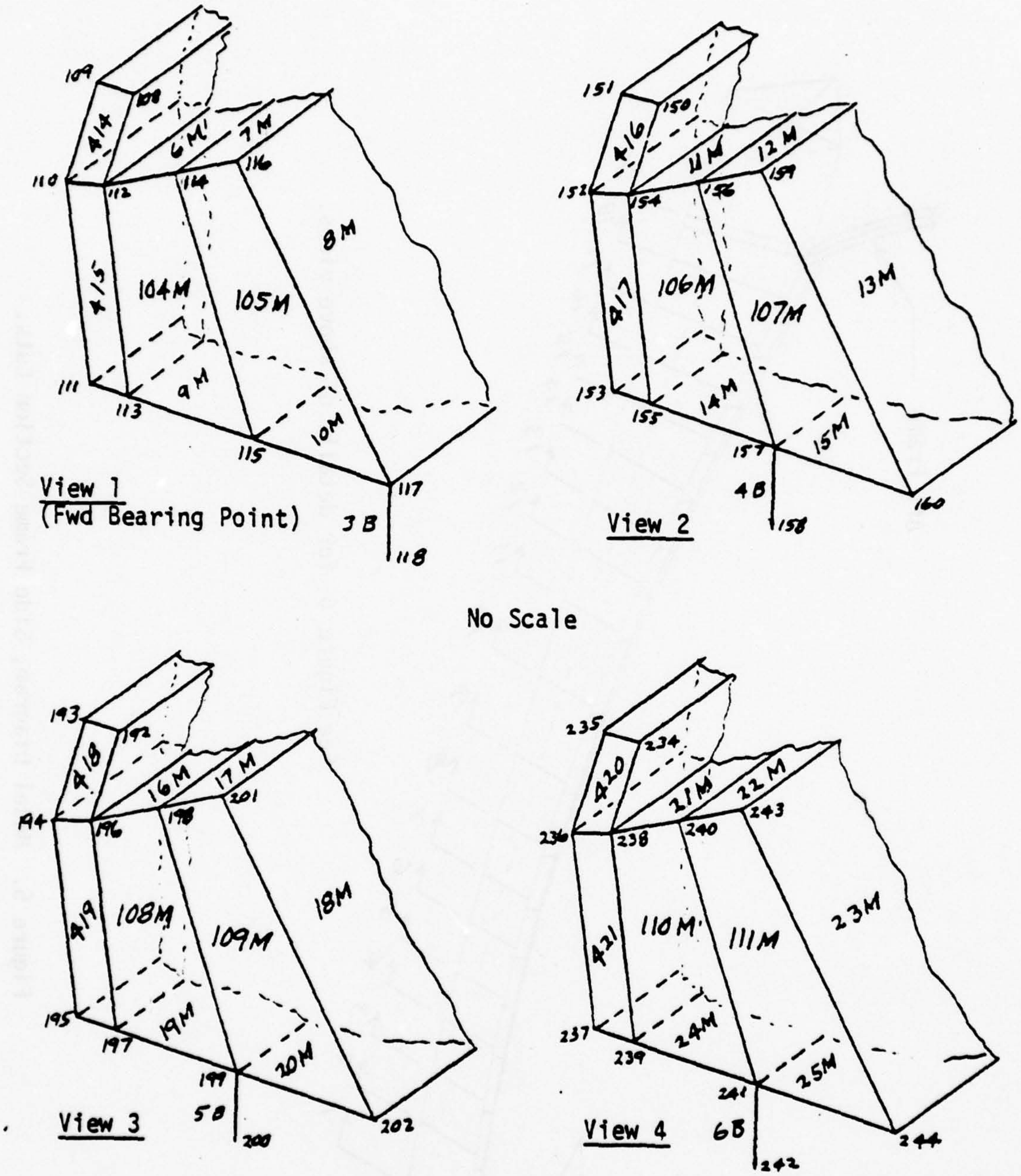


Figure 6. Model Diagram, Side Frame Sections.

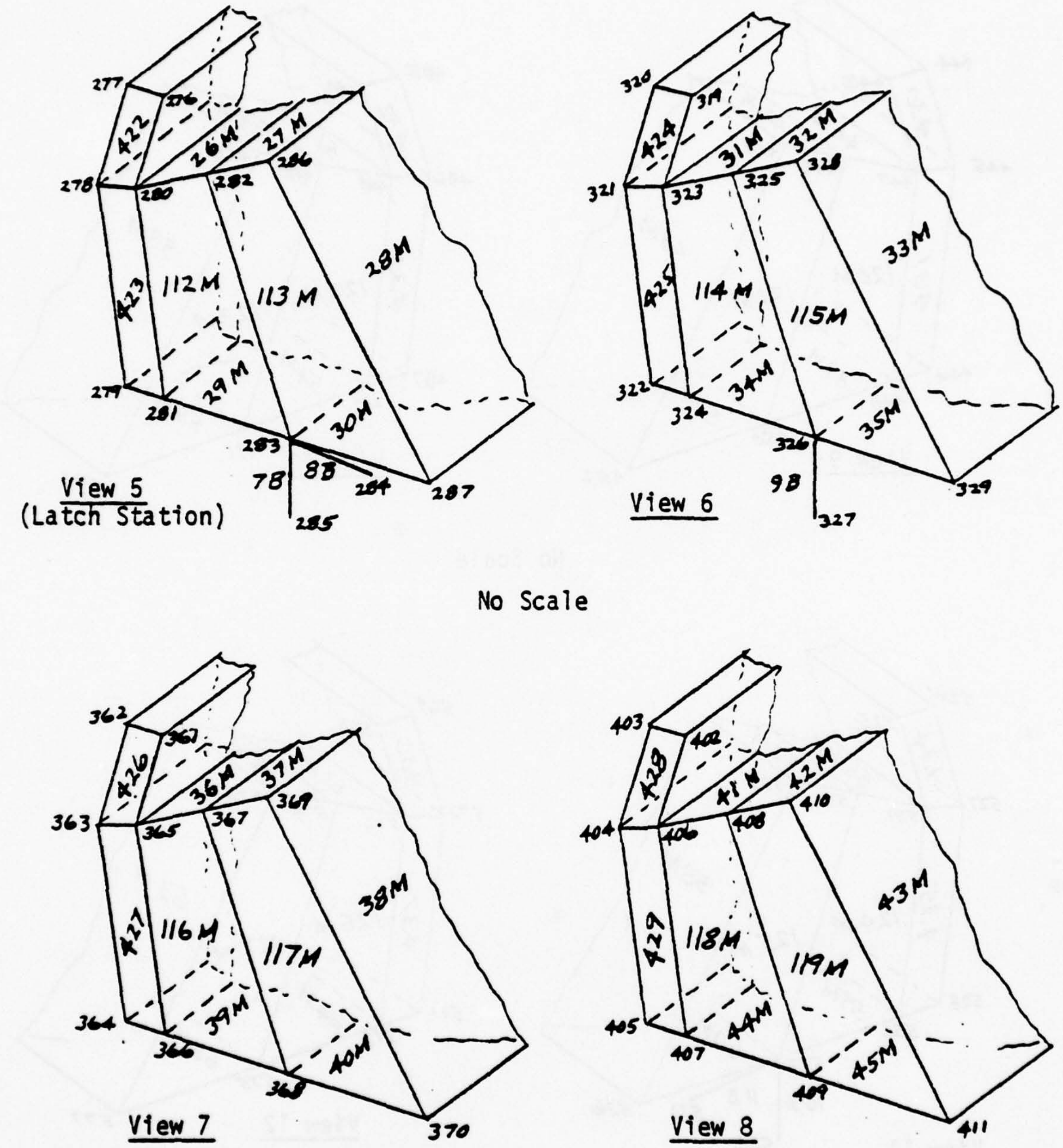


Figure 6. (Continued)

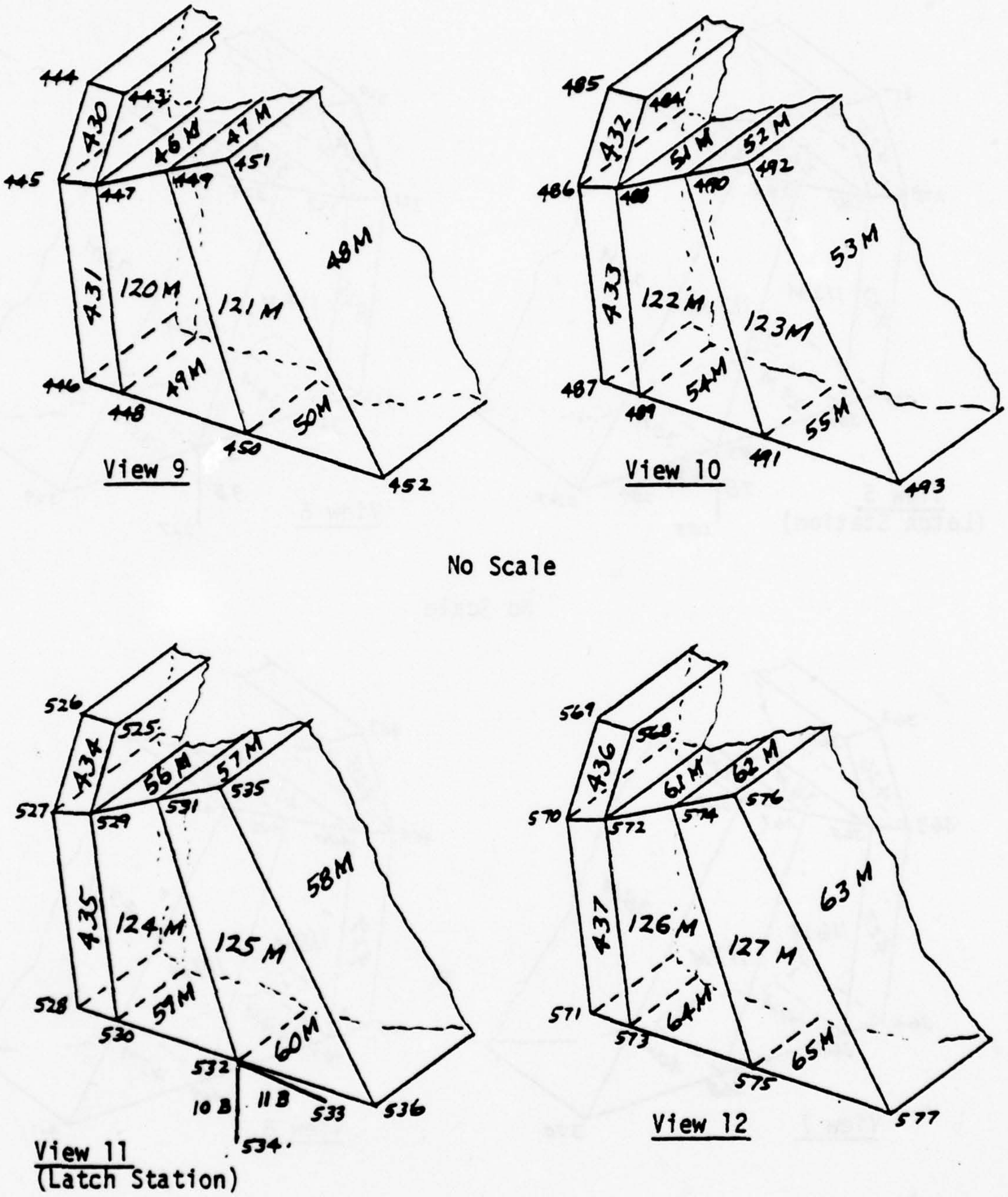


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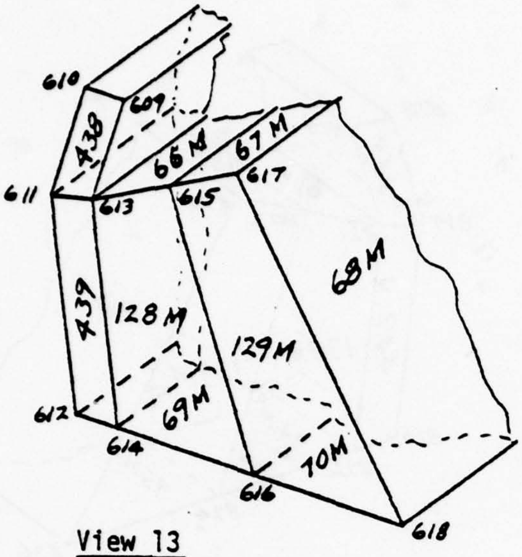
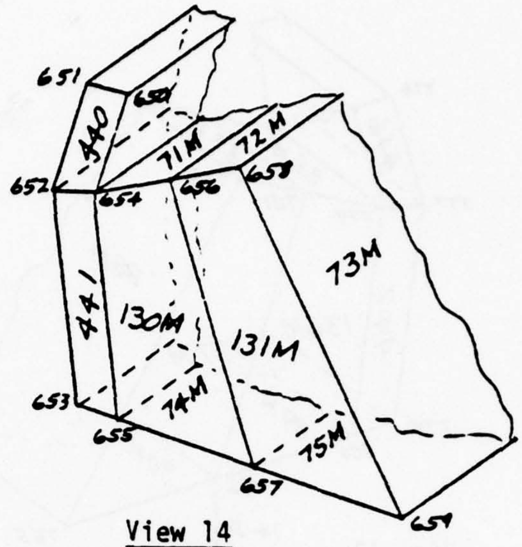
Figure 6. (Continued)

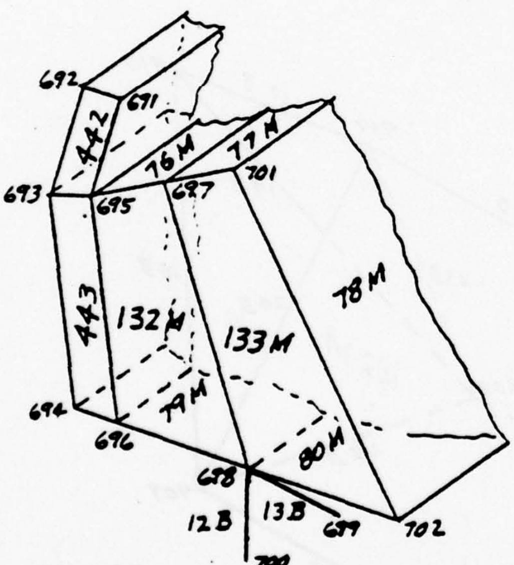


View 13

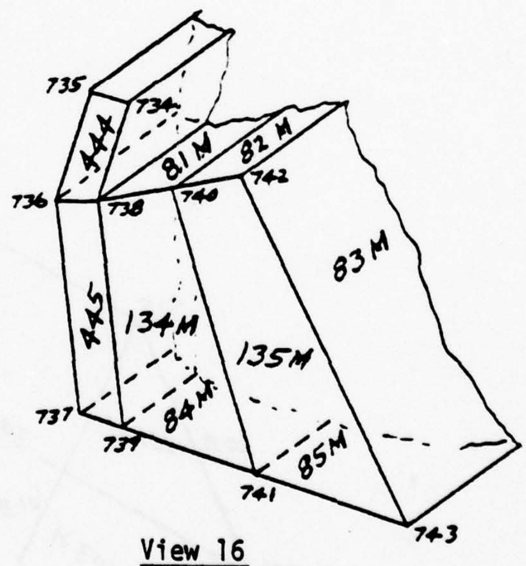


View 14

No Scale

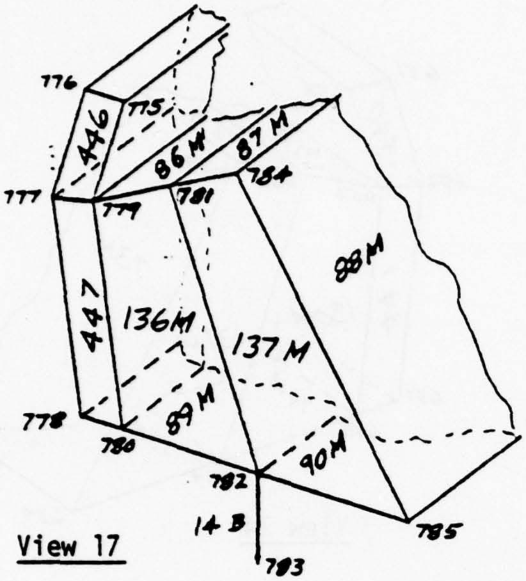


View 15
(Latch Station)

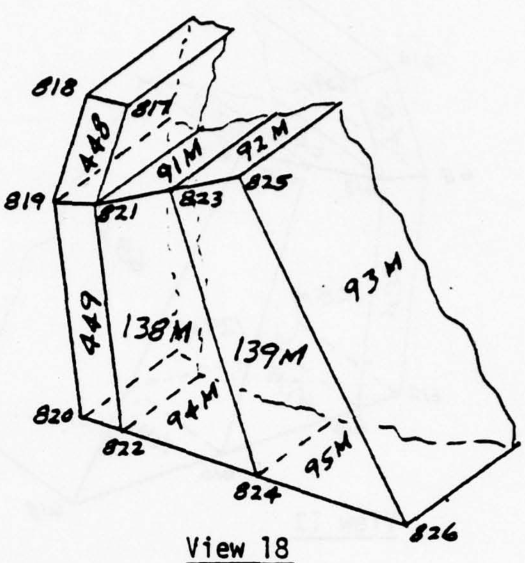


View 16

Figure 6. (Continued)

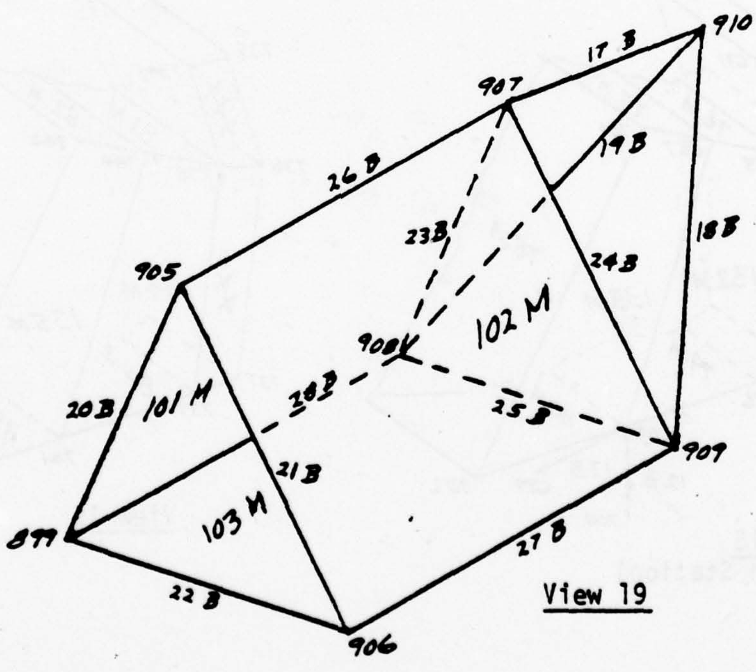


View 17



View 18

No Scale



View 19

Figure 6. (Continued)

Cell Elements
452 thru 460

Membranes
96 thru 100 and
140 thru 143

Bars 15 and 16

No Scale

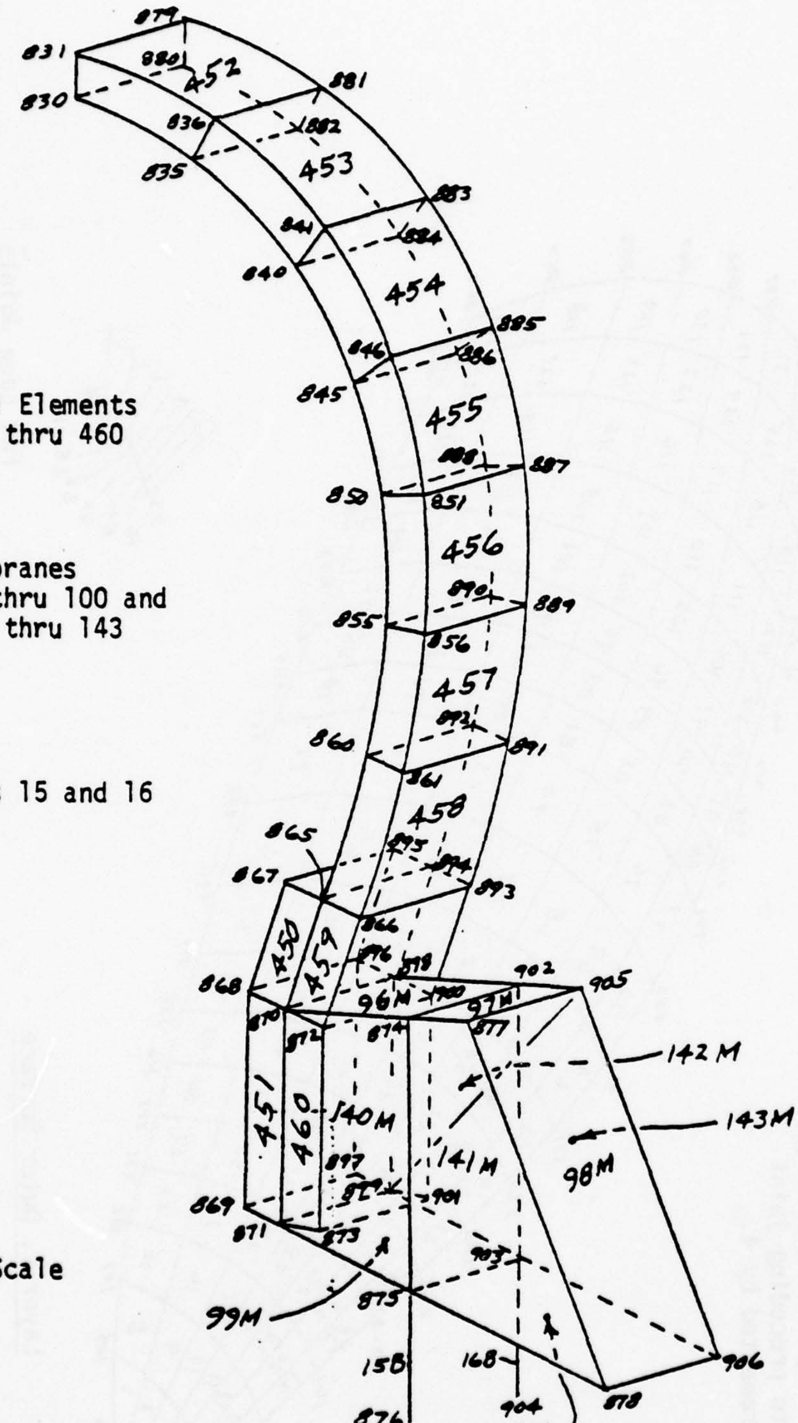


Figure 7. Model Diagram, Aft Frame.

Cell elements 1 thru 133

Edge joint numbers are shown.
Interior joint numbers (circumferentially from top ℄ sym to lower edge) are equal to preceding joint number incremented by 4.

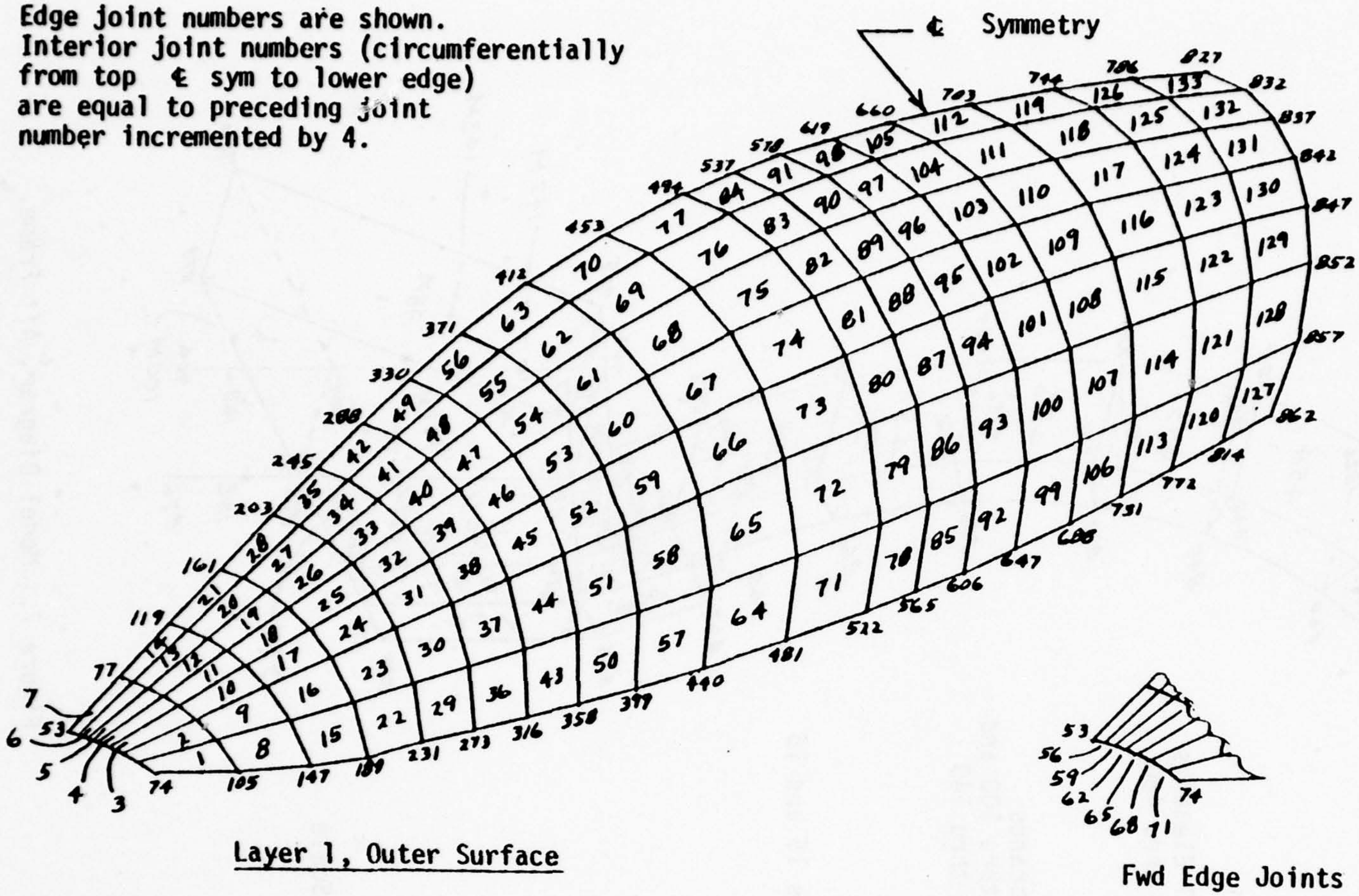
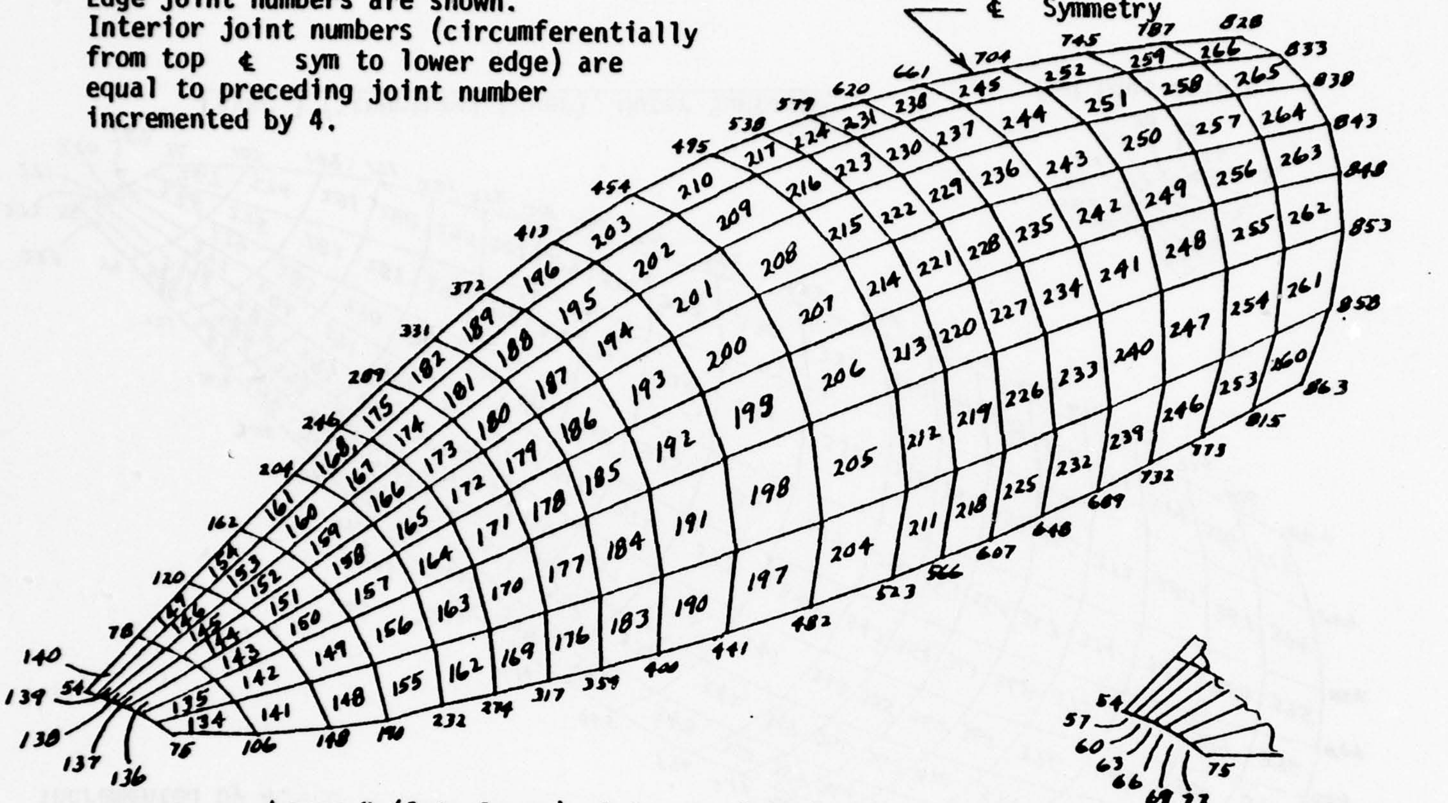


Figure 8. Model Diagram, Transparency Layers.

Cell Elements 134 thru 266.

Edge joint numbers are shown.
Interior joint numbers (circumferentially from top ℄ sym to lower edge) are equal to preceding joint number incremented by 4.



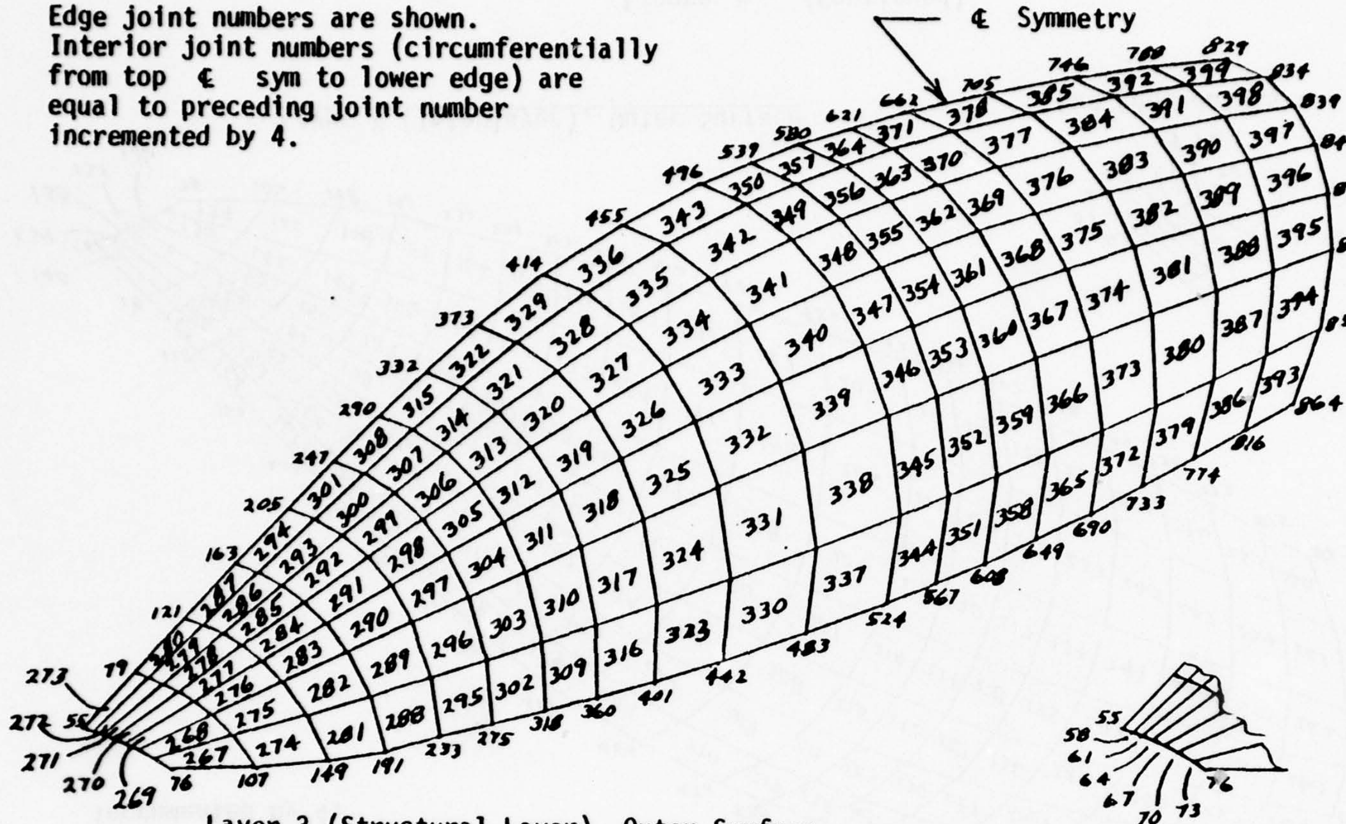
Layer 2 (Interlayer), Outer Surface

Fwd Edge Joints

Figure 8. (Continued)

Cell Elements 267 thru 399

Edge joint numbers are shown.
Interior joint numbers (circumferentially from top ℄ sym to lower edge) are equal to preceding joint number incremented by 4.



Layer 3 (Structural Layer), Outer Surface

Fwd Edge Joints

Figure 8. (Continued)

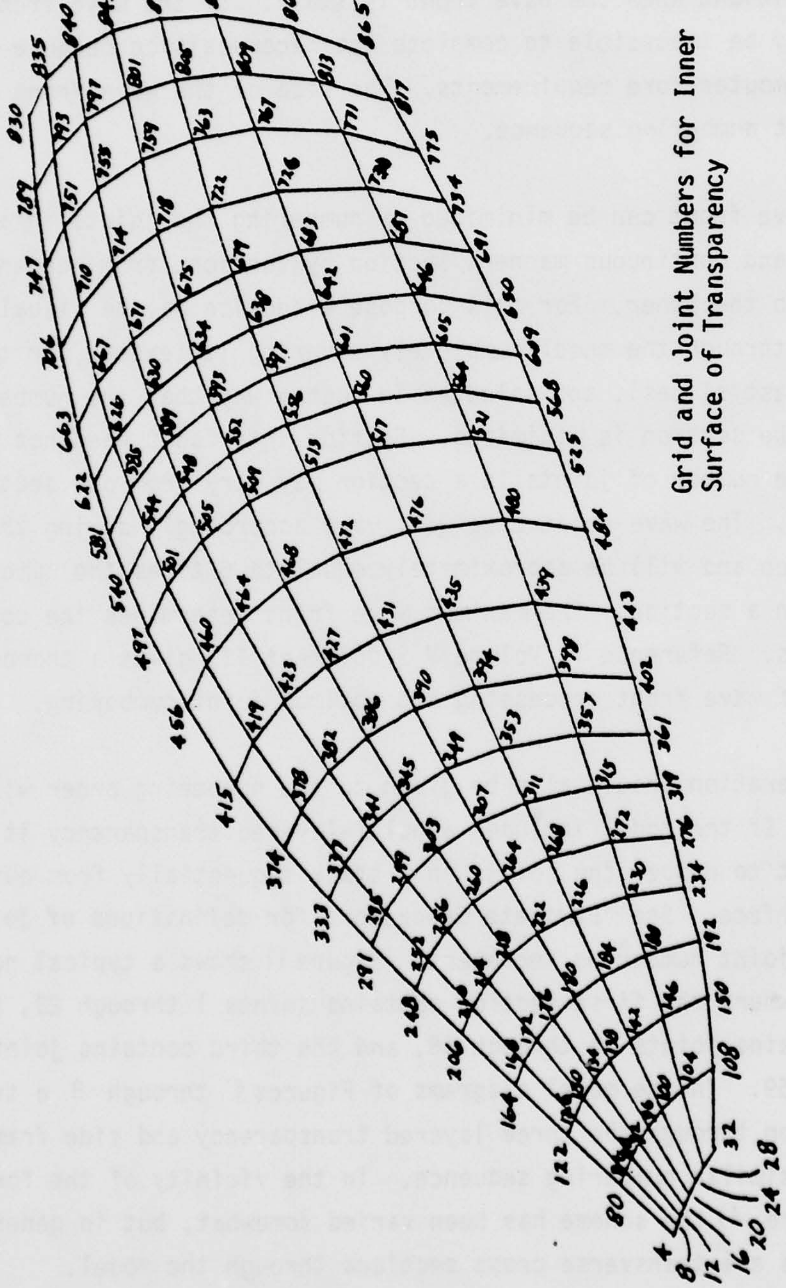


Figure 8. (Continued)
Grid and Joint Numbers for Inner
Surface of Transparency

Joint Numbering

The order in which joints are numbered is important. Decomposition of the stiffness matrix is based on a wave front technique which is most efficient when the wave front is small. If the wave front is too large it may be impossible to complete the decomposition because of prohibitive computer core requirements. The size of the wave front is related to the joint numbering sequence.

The wave front can be minimized by numbering the joints in a systematic and continuous manner, section by section, from one end of the model to the other. For this purpose a section may be visualized as a slice through the model completely severing it (except for the first and last slices), and selected in such a way that the number of joints in the section is minimized. Section interfaces need not be planes. The number of joints in a section may vary from one section to the next. The wave front size will vary accordingly during the decomposition and will be approximately equal to 6 times the number of joints in a section. The maximum wave front determines the core requirements. Reference 1, Volume V Supplement II, gives a thorough treatment of wave front processing and optimum joint numbering.

Consideration should also be given to the numbering order within a section. If the model includes a multi-layered transparency it is usually best to number the joints in a stack sequentially from outer to inner surface. See "Laminate Generator" for definitions of joint stacks and joint numbering increment. Figure 11 shows a typical numbering scheme where the first section contains joints 1 through 23, the second contains joints 24 through 46, and the third contains joints 47 through 69. In the model diagrams of Figures 4 through 8 a transverse section through the three layered transparency and side frame exhibits a similar numbering sequence. In the vicinity of the forward frame (Figure 4) the scheme has been varied somewhat, but in general the sections are transverse cross sections through the model.

Element Numbering

Each of the four types of finite elements (bar, membrane, cell, and point mass) has its individual numbering sequence. In Figures 4 through 8 bars are numbered 1 through 28, membranes are 1 through 143, and cells are 1 through 460. There are no special rules governing the numbering of bar, membrane and point mass elements. Any systematic sequence that the user considers convenient may be used. In numbering cell elements the user must consider Laminate Generator operations and number the transparency surface elements so that inner layer element numbers may be derived by adding a constant numbering increment. Refer to the definitions and discussions under "Laminate Generator" for further information. In Figure 8 the surface cell elements are numbered 1 through 133, the second layer 134 through 266, and the third layer 267 through 399. Therefore, the numbering increment from one layer to the next is 133.

MATERIAL PROPERTIES

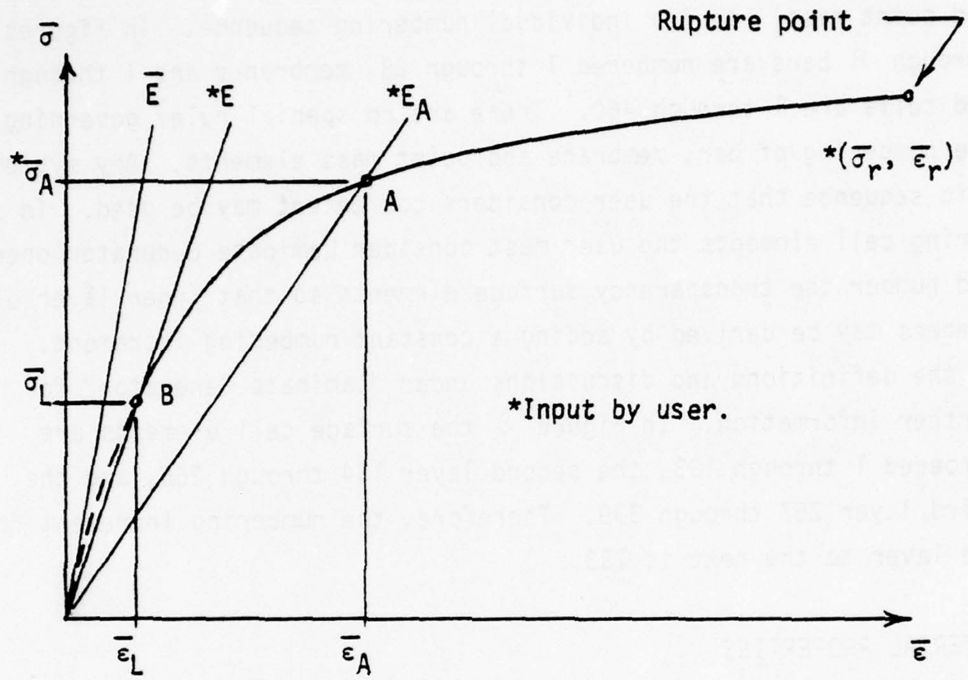
Table 5 lists the ten properties which must be input for each material used in the model. Reference 3 contains the results of specialized testing to determine the mechanical properties for polycarbonate materials. Standard handbooks are used for metals.

Ramberg-Osgood

The IMPACT program uses a Ramberg-Osgood representation of the true stress/true strain curve, see Figure 9. The analytic expression of the curve is:

$$\bar{\varepsilon} = \frac{1}{\bar{E}}\left[\bar{\sigma} - \bar{\sigma}_A\left(\frac{\bar{\sigma}}{\bar{\sigma}_A}\right)^n\right] + \frac{\bar{\sigma}_A}{E_A}\left(\frac{\bar{\sigma}}{\bar{\sigma}_A}\right)^n \tag{5}$$

The program uses input values for E, E_A, $\bar{\sigma}_A$, $\bar{\sigma}_r$ and $\bar{\varepsilon}_r$ to calculate the parameters n, $\bar{E}$ and $\bar{\sigma}_L$. These parameters are required for material nonlinearity considerations. As mentioned in the INTRODUCTION, the material nonlinearity code is not complete, but these basic calculations are coded,



$\bar{E}$ = slope tangent to Ramberg-Osgood curve at $\bar{\sigma} = 0$, $\bar{\varepsilon} = 0$.

E = slope of linear part of curve (Young's modulus).

E_A = secant modulus at point A, approximate yield point.

$\bar{\sigma}_L$, $\bar{\varepsilon}_L$ = true stress and strain at elastic limit.

$\bar{\sigma}_A$, $\bar{\varepsilon}_A$ = true stress and strain at approximate yield point.

$\bar{\sigma}_r$, $\bar{\varepsilon}_r$ = true stress and strain at rupture.

Figure 9. Ramberg-Osgood True Stress/True Strain Curve.

and the program expects a complete set of material properties for each material. Reference 3 provides properties 1 through 9 for polycarbonate and interlayer materials. For metals, assume that point A in Figure 9 is the intersection of the standard .002 offset line with the stress/strain curve at the yield stress F_{ty}. Then

$$\bar{\sigma}_A = F_{ty} \tag{6}$$

$$\frac{\bar{\sigma}_A}{E_A} = \frac{\bar{\sigma}_A}{E} + .002 \tag{7}$$

Combining equation 6 and 7 and solving for E_A gives

$$E_A = \left(\frac{F_{ty}}{.002E + F_{ty}} \right) E \tag{8}$$

From Reference 3 the expressions for true stress and true strain are evaluated at the rupture stress F_{tu} and the rupture strain e to give:

$$\bar{\sigma}_r = \left(1 + e - \frac{F_{tu}}{E} \right) F_{tu} \tag{9}$$

$$\bar{\epsilon}_r = \ell n \ (1 + e) \tag{10}$$

Property number 10, the damping to stiffness ratio will probably have to be estimated for metals, unless test data is available. For polycarbonate and interlayer materials values for the damping ratio are available from Reference 4, where a method based on combined testing and analytical procedures was used to determine damping ratios for several materials.

It is sometimes desirable to specify elastic material properties. For example, glass and some interlayer materials exhibit negligible plastic characteristics. In such a case the user may establish the values for E and $\bar{\sigma}_r$ and set

$$E_A = E, \ \bar{\sigma}_A = \bar{\sigma}_r, \ \bar{\epsilon}_r = \frac{\bar{\sigma}_r}{E} \tag{11}$$

The program will recognize this as a special situation, and as a result some of the calculations oriented toward material nonlinearity (plasticity) will be eliminated. The user may recognize that since material nonlinearity capability is not fully operational anyway, he may use this elastic option as a way to simplify input until such time as material nonlinearity is completed.

Strain Rate Dependence

The program does not automatically account for continually changing strain rates in all elements of the model. This is thought to be prohibitive. Instead the user estimates the expected strain rate and inputs material properties that are consistent with the estimated strain rate.

Temperature Dependence

If values of the material properties are available at more than one temperature the user will have an indication of temperature dependence. As explained in Section III under INPUT DATA REQUIREMENTS, Data Code Descriptions, Data Code 10, as many temperature and property value pairs as are available may be input for each property. The program then uses the input temperature/value pairs in a least squares curve fitting procedure to calculate a specified number of coefficients for a polynomial equation which defines the property as a function of temperature. An alternate option allows the user to input the coefficients of the polynomial equation directly if he so desires. The first coefficient is the value of the property when there is no temperature dependence. Subsequent coefficients introduce temperature effects in terms of powers of the temperature of the finite element being processed. The program calculates finite element temperatures from joint temperature data which the user inputs on data code 2 or 3 cards. Note that when no temperature dependence is being specified the second option should be used to input only the first coefficient which is then equal to the value of the property.

LIMITATIONS AND COMPUTING TIME

Model size limitations are given in Table 1. In general these limits should allow the user to model a structure with as much detail as practicable from the standpoint of computing time.

TABLE 1. MODEL SIZE LIMITATIONS

ITEM	MAXIMUM NUMBER
Joints	1200
Direction Cosines	50
Constraints	600
Materials	20
Element Forces	20000
Edge Degrees of Freedom	3000

In the discussion under "Joint Numbering" it was pointed out that the wave front during decomposition of the stiffness matrix should be kept as small as possible to minimize computer core requirements. Table 2 gives approximate correspondence between wave front and core requirement.

TABLE 2. WAVE FRONT AND COMPUTER CORE

WAVE FRONT	CORE REQUIREMENT (CM)
140	100,000
280	200,000
370	300,000

Table 3 is presented to give the user a basis for estimating computer time. The tabulated values are actual run times on the CDC Computer.

TABLE 3. CDC COMPUTER TIME, SECONDS

<table>
<tr><td rowspan="7">Model Size</td><td>Joints</td><td>910</td><td>599</td><td>16</td></tr>
<tr><td>Bars</td><td>28</td><td>0</td><td>2</td></tr>
<tr><td>Membranes</td><td>143</td><td>0</td><td>2</td></tr>
<tr><td>Cells</td><td>460</td><td>215</td><td>2</td></tr>
<tr><td>Deg. of Freedom</td><td>4999</td><td>3042</td><td>76</td></tr>
<tr><td>Modes</td><td>30</td><td>30</td><td>10</td></tr>
<tr><td>Wave Front</td><td>253</td><td>172</td><td>--</td></tr>
<tr><td colspan="2">Laminate Generator</td><td>30 CPU</td><td>11 CPU</td><td rowspan="10">Small model, all steps combined in one computer run for 10 time increments.

30 CPU
80 I/O</td></tr>
<tr><td colspan="2">Loads Generator</td><td>15 CPU</td><td>14 CPU</td></tr>
<tr><td colspan="2">Initial Generator</td><td>537 CPU
1098 I/O</td><td>245 CPU
401 I/O</td></tr>
<tr><td colspan="2">Decomposition</td><td>4066 CPU
7324 I/O</td><td>1000 CPU
1800 I/O</td></tr>
<tr><td colspan="2">Modal Transformation</td><td>5240 CPU
8320 I/O</td><td>2000 CPU
3200 I/O</td></tr>
<tr><td colspan="2">Data Files for Inc Sol</td><td>600 CPU
1500 I/O</td><td>250 CPU
600 I/O</td></tr>
<tr><td colspan="2">Linear Incremental Sol</td><td>750+20/Inc
1250+35/Inc</td><td>292+9/Inc
500+15/Inc</td></tr>
<tr><td colspan="2">Nonlinear Incremental Sol</td><td>---</td><td>100+430/Inc
100+280/Inc</td></tr>
<tr><td colspan="2">Postprocessor</td><td>37 CPU
474 I/O</td><td>25 CPU
320 I/O</td></tr>
</table>

KEY-PUNCH DATA FORMS

The following seven pages are suggested forms on which the user may list model definition data in order to have it keypunched to data cards. These forms are consistent with the descriptions given in SECTION III under "Data Code Descriptions." Note that the same data card format may be applicable to more than one data code. For example, data codes 1 through 5 all require the same data card format. The user may copy these forms as needed, or he may use them as a guide to design his own forms.

FORM - DATA CODE 1 THRU 5

DAC 25 1212C (REV 8 69)

RIGHT ADJUSTED INTEGER DATA					FLOATING POINT DATA				TYPE OF DATA
1					BASE TEMPERATURE T_B	MECH EQUIV OF HEAT J			CONSTANTS
2	JOINT				X - COORDINATE	Y - COORDINATE	Z - COORDINATE	JT TEMP T_J	JOINT COORD'S
3	JOINT a	JOINT b						JT TEMP T_J	JOINT TEMP'S
4	DIR NO	JOINT m	JOINT n		X DIR COSINE ℓ_x	Y DIR COSINE ℓ_y	Z DIR COSINE ℓ_z		DIRECTION NO'S
5	CONSTR	JOINT m	JOINT n	DIR NO	ℓ_x	ℓ_y	ℓ_z		CONSTRAINTS
1 2	3 4 5 6	7 8 9 10	11 12 13 14	15 16 17 18	19 20 21 22 23 24 25 26 27 28 29 30 31 32 33	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56 57 58 59 60 61 62 63	64 65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

FORM - DATA CODE 7

DAC 25-1212C (REV 8-69)

DATA CODE 7, LAMINATE DEFINITION DATA

RIGHT ADJUSTED INTEGER DATA					FLOATING POINT DATA	
7	L				t_0	
7	L + ℓ	M_ℓ	ΔJ_ℓ	ΔE_ℓ	t_ℓ	
7	L + 99					

FORM - DATA CODE 8

DAC 25 1212C (REV 8 69)

DATA CODE 8, LAMINATE VARIABLE THICKNESS DATA

RT ADJ INTEGER			FLOATING POINT DATA						
8	JTa	JTb	t_1	t_2	t_3	t_4	t_5	t_6	
1 2	3 4 5 6	7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60	61 62 63 64 65 66 67 68 69 70	71 72 73 74 75 76 77 78 79 80

FORM - DATA CODE 10

Cols 1–2	Cols 3–6	Cols 7–8	Cols 9–10	Cols 11–20	Cols 21–30	Cols 31–40	Cols 41–50	Cols 51–60	Cols 61–70	Cols 71–72	Cols 73–80
RT ADJ INTEGER				ALPHAMERIC DATA				Card column 72 non-blank for continuation			
1 0	M			MATERIAL DESCRIPTION							
RT ADJ INTEGER				FLOATING POINT DATA							TYPE OF DATA
1 0	M + P		NC	T_1	V_1	T_2	V_2	T_3	V_3		TEMP-VAL PAIRS
1 0	M + P	NI		a_0	a_1	a_2	a_3	a_4	a_5		POLYNOM COEF'S
1 0	M + 99	End of data for material M									
1 2	3 4 5 6	7 8	9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48 49 50	51 52 53 54 55 56 57 58 59 60	61 62 63 64 65 66 67 68 69 70	71 72	73 74 75 76 77 78 79 80

FORM - DATA CODE 11

RT ADJUSTED INTEGER DATA					FLOATING POINT DATA			
1 1	1	$3n_1$			m	v	L	DATA CODE 11,
1 1	2	$n_{1\beta}$			b_x	b_y	b_z	BIRD IMPACT DEFINITION DATA
1 1	3				n_x	n_y	n_z	
1 1	4				d_x	d_y	d_z	
1 1	5				X_o	Y_o	Z_o	
1 1	6	β			D	f		
1–2	3–6	7–10	11–14	15–18	19–33	34–48	49–63	64–80

FORM - DATA CODE 12

DAC 25-1212C (REV 8-69)

DATA CODE 12, IMPACT FOOTPRINT DATA

RIGHT ADJUSTED INTEGER DATA

Card column 72 non-blank for continuation

1 2	β	$j_{1\beta}$	$j_{2\beta}$	$j_{3\beta}$	$j_{4\beta}$	$j_{5\beta}$	$j_{6\beta}$	.	.	.	.	.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

FORM - DATA CODE 20, 30, 40, 50

DAC 25 1312C (REV 8-69)

ELEMENT DEFINITION DATA

RIGHT ADJUSTED INTEGER DATA											FLOATING POINT DATA			TYPE OF DATA
2 0	BAR NO	p	q							M	AREA A			BAR ELEMENT
3 0	MEM NO	p	q	r	s					M	THICKNESS t	ζ_{pq}		MEMBRANE ELEM
4 0	CELL NO	p_0	q_0	r_0	s_0	p_1	q_1	r_1	s_1	M		ξ_{pq}		CELL ELEMENT
5 0	PT MASS	p									M_{px}	M_{py}	M_{pz}	POINT MASS ELEM
1 2	3 4 5 6	7 8 9 10	11 12 13 14	15 16 17 18	19 20 21 22	23 24 25 26	27 28 29 30	31 32 33 34	35 36 37 38	39 40 41 42	43 44 45 46 47 48 49 50 51 52	53 54 55 56 57 58 59 60 61 62	63 64 65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

SECTION III
USING THE PROGRAM

The use of the IMPACT computer program is described in this section.

FUNCTIONAL FLOW CHART

Figure 10 shows the sequential steps the user follows in the application of the IMPACT program. User generated card input data is primarily finite element model definition data but also includes all the rest of the card input that will be required during the course of the analysis. The preparation of input data cards is described in detail in the subsection INPUT DATA REQUIREMENTS.

The CDC UPDATE procedure may be used to input the model definition card deck and store it in an UPDATE data file. UPDATE may be used also to edit a model data file and to input model data to the Laminate Generator, Loads Generator, or Initial Generator programs. Optionally, the user may input the model definition cards directly to these programs.

The Laminate Generator program is designed to read a partial model definition deck and generate the missing data to form a complete model definition. The Loads Generator program extracts the necessary information from a model definition deck to generate bird impact loads. Functions identified to this point are referred to as "preprocessing" functions, and the modules involved are collectively termed the Preprocessor.

The Initial Generator reads a complete model definition deck and generates the structural matrices and information lists required in subsequent analysis steps. Structural mass generation, stiffness decomposition, vibration mode extraction and modal transformation are performed by the FORMAT program, which is described in Reference 1. FORMAT is also used to produce properly ordered data files for input to the incremental solution. The Incremental Solution code calculates the modal response and element forces, stresses and strains for the specified time points, and finally the post processor prints out selected information for use in evaluating results.

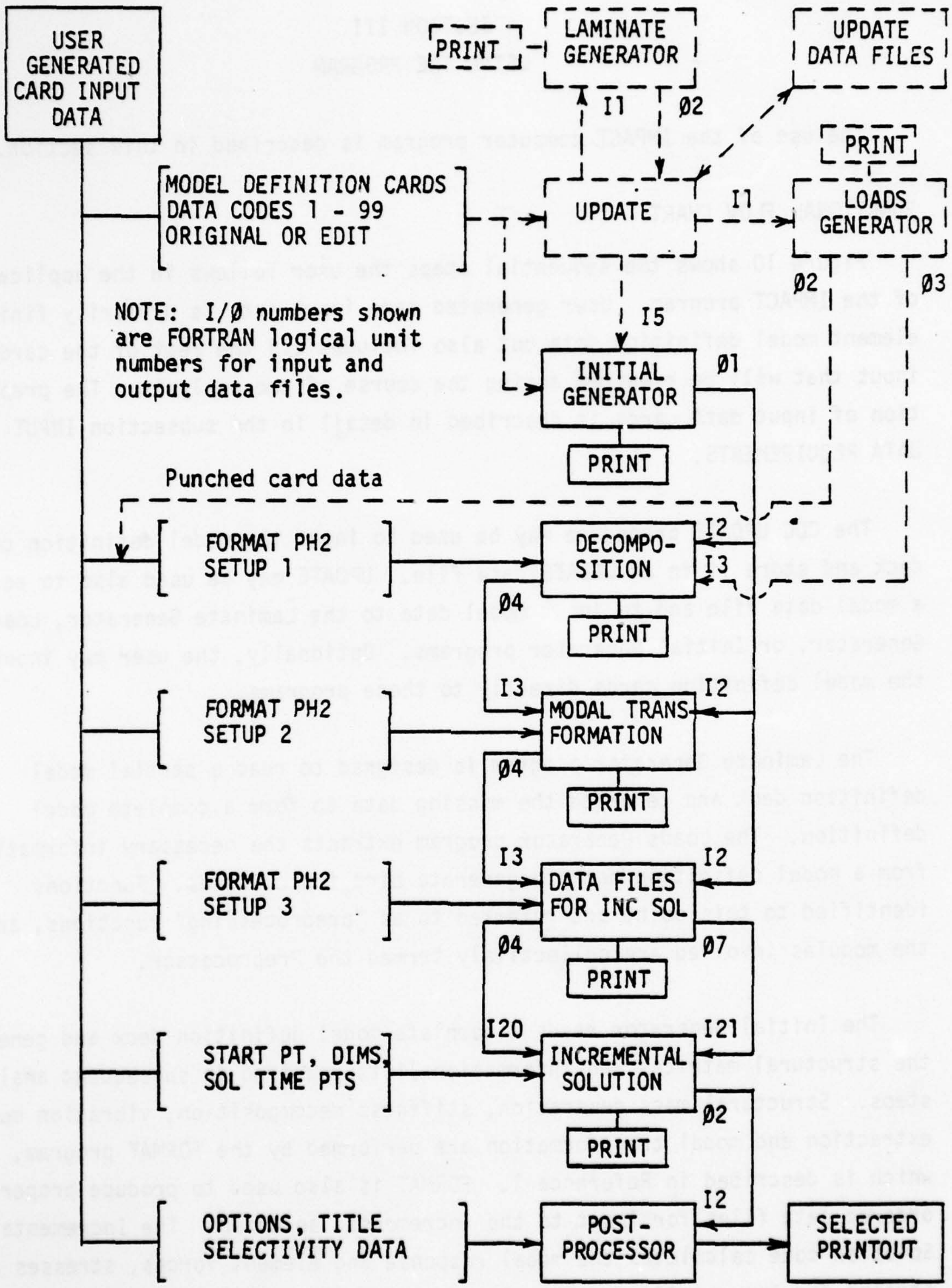


Figure 10. IMPACT Functional Flow Chart.

Detailed discussions of the functions shown in Figure 10 are presented in the following subsections. Appendix A contains an example deck setup including JCL.

INPUT DATA REQUIREMENTS

User generated card input data is described in this subsection.

Data Code Descriptions

Model definition data for the IMPACT program is identified by a data code entered in card columns 1 and 2 of each card. The data code is an integer value in the range 1 through 99. The following pages give the data code designation, type of data, input card format, and descriptions of the data to be entered in each field of the input card. Card diagrams for each data code show general headings which indicate whether the data to be entered is integer or floating point, then the card fields are marked off with a pre-entered data code in card columns 1, 2 and field heading symbols shown in applicable fields (unused fields are crossed out), and finally the beginning card column is identified at the left side of each field. In some cases, the ending card column for a field is also shown for clarity. Definitions of the field heading symbols are listed following the card diagram.

A data code deck consists of as many cards as necessary to input the type of data identified by a given data code followed by an end card having the data code and four nines entered in card columns 1 through 6. A model definition deck is made up of applicable data code decks stacked in the order of increasing data codes. A complete model definition deck as required by the Initial Generator program must include data codes decks indicated in Table 4. A data code deck

may be nothing more than the end card if that type of data is not needed to define a particular model, but the end card must be present as a minimum. Note that some data code decks are optional. However, a complete model definition deck will not be output from the Laminate Generator unless all the optional data code decks are input.

TABLE 4. MODEL DEFINITION DATA CODE SUMMARY

DATA CODE	TYPE OF DATA	GENERATOR PROGRAMS		
		LAMINATE	LOADS	INITIAL
1	Constants	OPT	OPT	REQ
2	Joint Coordinates	REQ, GEN	REQ	
3	Joint Temperatures	OPT	OPT	
4	Direction Number Definitions	OPT		
5	Joint Constraint Definitions	OPT		REQ
6	Surface Normal Vectors	GEN		OPT
7	Laminate Definition Data	REQ		-
8	Laminate Variable Thickness Data	OPT	OPT	-
9	- Not Used -	-	-	-
10	Material Properties	OPT	OPT	REQ
11	Bird Impact Definition Data	OPT	REQ	OPT
12	Impact Footprint Joint List	OPT	REQ	OPT
13-19	- Not Used -	-	-	-
20	Axial Bar Element Definition	OPT	OPT	REQ
21-29	- Not Used -	-	-	-
30	Membrane Element Definition	OPT	OPT	REQ
31-39	- Not Used -	-	-	-
40	Cell Element Definition	REQ, GEN	OPT	REQ
41-49	- Not Used -	-	-	-
50	Point Mass Element Definition	OPT	OPT	REQ
51-99	- Not Used -	-	-	-

REQ = required

OPT = optional

GEN = generated by program

REQ, GEN = basic data required to be input, additional data is generated by program

- = must not be present

Data Code 1, Constants

User inputs two data cards and one end card.

RT ADJ INTEGER					FLOATING POINT			
1					a	b		
1 2	3	7	11	15	19	34	49	64 72

19999 End Card

Card 1

a = base temperature T_B (such as room temperature) for the analysis

b = mechanical equivalent of heat J (example: $J = 4.184 \times 10^7$ ergs/calorie)

Card 2

$a = 1.0 \times 10^6$

= bar compliance coefficient (part of material nonlinearity capability for which code is incomplete, but a value for "a" is required)

$b = 1.0 \times 10^{-12}$

= stiffness suppression coefficient (eliminates insignificant values in stiffness matrix)

Note: Values for "a" and "b" are currently required to be input by user, but eventually should be built into code.

Data Code 2, Joint Coordinates

User inputs one card for each joint and one end card. See pages 11 and 76 for discussions of joint coordinates.

RT ADJ INTEGER					FLOATING POINT			
2	JT				X	Y	Z	T_J
1 2	3	7	11	15	19	34	49	64 72
2	9999	End Card						

JT = joint identification number (<9999)

X, Y, Z = X, Y, Z coordinates of the joint in the right hand cartesian coordinate system of the model

T_J = temperature of the structure at the joint location. (This temperature implies thermal deformations if different from the base temperature specified in data code 1.)

Data Code 3, Joint Temperature

This data overrides temperatures previously input on data code 2 cards. The user inputs data cards as necessary and one end card.

RT ADJ INTEGER					FLOATING POINT			
3	JTa	JTb						T_J
1 2	3	7	11	15	19	34	49	64 72

3	9999	End Card

JTa = joint number

JTb = optional entry of joint number to define a range of joint numbers JTa to JTb, inclusive

T_J = temperature of the structure at joint JTa or at all joints in the range JTa through JTb, if JTb is input

Data Code 4, Direction Number Definitions

User inputs one card for each direction number and one end card.

RT ADJ INTEGER					FLOATING POINT			
4	DIR	JTm	JTn		ℓ_X	ℓ_Y	ℓ_Z	
1 2	3	7	11	15	19	34	49	64 72

49999	End Card

DIR = direction identification number (1,2,3,...)

Option 1: Enter joint numbers JTm and JTn to define the direction parallel to the vector JTm to JTn

Option 2: Enter direction vector components ℓ_X, ℓ_Y, ℓ_Z (need not be normalized) to define the direction

Note: This data provides a table of direction numbers which can be referenced to define the direction of joint constraints in data code 5. It is particularly convenient when a large number of constraints are oriented in the same direction.

Data Code 5, Joint Constraint Definitions

The joint will be constrained against displacement in the given direction. User inputs one card for each constraint and one end card. See page 14 for discussion of constraints.

RT ADJ INTEGER					FLOATING POINT			
5	CON	JTm	JTn	DIR	ℓ_X	ℓ_Y	ℓ_Z	
1 2	3	7	11	15	19	34	49	64 72

59999	End Card

CON = constraint identification number (1,2,3,...)

JTm = number of the joint to be constrained

Option 1: Enter joint number JTn to define the constraint direction parallel to the vector JTm to JTn

Option 2: Enter a direction number DIR to reference a direction defined in Code 4 data

Option 3: Enter direction vector components ℓ_X, ℓ_Y, ℓ_Z (need not be normalized) to define the constraint direction

Data Code 6, Surface Normal Vectors, reference Figure 11.

This data is generated by the laminate generator program but may be edited or input by cards.

RT ADJ INTEGER					FLOATING POINT			
6	JTs				n_X	n_Y	n_Z	A_S
1 2	3	7	11	15	19	34	49	64 72

69999	End Card

JTs = joint number of a joint on the surface of the laminate

n_X, n_Y, n_Z = X, Y, Z components of a unit vector normal to the surface at joint JTs and pointing into the laminate

A_S = surface area of a section of the laminate associated with joint JTs, reference Figure 11

Data Code 7, Laminate Definition Data

User inputs cards as necessary to define a multi-layered laminate followed by one L+99 card and one end card. (See pages 75 through 80 for discussion of laminate data.

RT ADJ INTEGER					FLOATING POINT			
7	$L+\ell$	M_ℓ	ΔJ_ℓ	ΔE_ℓ	t_ℓ			
1 2	3	7	11	15	19	34	49	64 72

$\underbrace{M_\ell \;\; \Delta J_\ell \;\; \Delta E_\ell}$ blank for $\ell = 0$ and $t_\ell = t_o$

7	L+99

7	9999	End Card

L = laminate identification number (any multiple of 100 < 9900)

ℓ = layer number (0, 1, 2, 3, ...)

M_ℓ = material identification number for layer ℓ (M_ℓ is a reference to code 10 data)

ΔJ_ℓ = joint numbering increment for layer ℓ ($J_{in_\ell} = J_{out_\ell} + \Delta J_\ell$), see page 76

ΔE_ℓ = element numbering increment for layer ℓ ($E_\ell = E_{\ell-1} + \Delta E_\ell$), see page 78

t_ℓ = thickness of layer ℓ

= surface offset t_o when $\ell = 0$

Note: A model of a windshield system could contain more than one laminated transparency (windshield, side window, etc.). The laminate identification number L provides for identifying each laminate by a user assigned number as defined above.

Data Code 8, Laminate Variable Thickness Data

User inputs cards as necessary to define variable thickness layers in a multi-layered laminate followed by one end card. See page 79.

RT ADJ INT			FLOATING POINT						
8	JTa	JTb	t_1	t_2	t_3	t_4	t_5	t_6	
1 2	3	7	11	21	31	41	51	61 70	

8	9999

End Card

JTa = surface joint number below which layer thicknesses $t_1, t_2, t_3, \cdots$ are to be used to override layer thicknesses specified in Code 7 data

JTb = surface joint number which, if present, defines a range of surface joint numbers JTa through JTb below which the layer thicknesses will be effective

Note: If there are more than six layers in the laminate, enter t_7 through t_{12} on a second card with card columns 1 through 10 duplicated from the first card. Continue this process as necessary.

Data Code 10, Material Properties

A set of cards M through M+99 is input for each material used in the structure. One end card follows the last set. See page 29 for discussion.

RT	ADJ	INT	ALPHAMERIC
10	M	X	Material name and descriptive information

RT	ADJ	INT		FLOATING POINT					
10	M+P	X	NC	T_1	V_1	T_2	V_2	T_3	V_3
10	M+P	NI	X	a_0	a_1	a_2	a_3	a_4	a_5
1 2	3	7	9	11	21	31	41	51	61 70

10	M+99

Card col 72 non-blank for continuation
No restrictions on symbol choice.

10	9999	End Card

M = user assigned material identification number (100, 200, ...) which can be referenced in element definition cards to specify the element material

P = property identification number (1, 2, 3, ...)

Either of two options may be used to input each material property as a function of temperature. Both options result in coefficients a_i of a polynominal equation for the value of the property V_p as a function of temperature T ($V_p = a_0 + a_1T + a_2T^2 + \ldots$)

Option 1

NC = number of polynominal coefficients to be computed by the program from the given (T_i, V_i) pairs

$\leq$ number of (T_i, V_i) pairs input

Data Code 10 (Cont.)

T_i, V_i = pairs of values where V_i is the value of the property P at the temperature T_i (i = 1, 2, 3, ···)

Option 2

NI = number of polynomial coefficients a_i to be input by the user as an alternate to inputting (T_i, V_i) pairs

a_i = coefficients of a polynomial equation which gives the value of the property P as a function of temperature (i = 0, 1, 2, 3, ···)

Currently, there are ten properties which must be input for each material using one of the two options described. Assigned property numbers P and the corresponding property descriptions are given in Table 5.

TABLE 5. MATERIAL PROPERTY IDENTIFICATION

P	Property Description	Symbol
1	Elastic modulus (Young's)	E
2	Secant modulus at point A	E_A
3	True stress at point A	$\bar{\sigma}_A$
4	True stress at rupture	$\bar{\sigma}_r$
5	True strain at rupture	ϵ_r
6	Poisson's ratio	ν
7	Coefficient of thermal expansion	α_T
8	Mass density (wt per unit vol. x 1/acc. of grav.)	ρ
9	Specific heat	s
10	Damping to stiffness ratio	h

The first five properties define the Ramberg-Osgood representation of the true stress-true strain curve, reference Figure 9. Current formulations are based on the assumption that the materials are isotropic. Sources for material properties are References 3 and 4. See also pages 29 through 31.

Data Code 11, Bird Impact Definition Data

User inputs cards as described below and one end card. See pages 81 through 88 for discussion, definitions and equations.

RT ADJ INTEGER					FLOATING POINT			
11	a	b	X	X	c	d	e	X
1 2	3	7	11	15	19	34	49	64 72

11	9999	End Card

Card 1

a = 1

b = row dimension for output matrix of incremental loads

= 3 x number of joints in the model

c = bird mass m

d = bird velocity v

e = effective length L , reference Figure 12

Card 2

a = 2

b = number of time increments n_{I_β} during which impact is applied

c, d, e = X, Y, Z components of unit vector $\vec{b}$ parallel to the bird path

Card 3

a = 3

b = not used

c, d, e = X, Y, Z components of a unit vector $\overline{n}$ normal to the surface of the structure at the impact point

Card 4

a = 4

b = not used

c, d, e = X, Y, Z components of a unit vector $\overrightarrow{d}$ in the same plane as $\overrightarrow{b}$ and $\overrightarrow{n}$, in the approximate direction of motion of the impact footprint, and normal to the desired direction of the resultant impact load, reference Figure 12.

Card 5

a = 5

b = not used

c, d, e = X, Y, Z coordinates of the impact point

Cards 6 (There are n_{I_β} of these cards)

a = 6

b = time increment identification number β (β = 1, 2, 3 $\cdots$, N_{I_β})

c = distance D_β traveled by the impact footprint in the time period from t_0 to $t_{\beta-1}$

d = load/time distribution factor f_β for increment β

e = not used

Data Code 12, Impact Footprint Joint List

User inputs n_{I_β} of these cards and one end card, see page 87.

RIGHT ADJUSTED INTEGER DATA

12	β	j_{1_β}	j_{2_β}	j_{3_β}	j_{4_β}	j_{5_β}	j_{6_β}	.	.	.							
1 2	3	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68

12	9999	End Card

Card col 72 non-blank for continuation

β = time increment identification number ($\beta = 1, 2, 3, \cdots, n_{I_\beta}$)

j_{i_β} = joint numbers of all joints to which the resultant bird impact force is to be distributed in the βth time increment

Data Code 20, Axial Bar Element Definition

User inputs one card for each bar and one end card. See pages 5 through 10 for discussion of finite elements.

RIGHT ADJUSTED INTEGER DATA											FLOATING POINT DATA		
20	N	p	q							M	A		
1 2	3	7	11	15	19	23	27	31	35	39	43	53	63 72

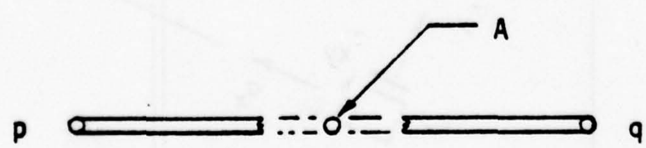
20	9999	End Card

N = bar identification number

p, q = joint numbers defining the ends of the bar

M = material identification number (references code 10 data)

A = cross-sectional area of the bar



Data Code 30, Membrane Element Definition

User inputs one card for each membrane and one end card. See pages 5 through 10 for discussion of finite elements.

RIGHT ADJUSTED INTEGER DATA											FLOATING POINT DATA		
30	N	p	q	r	s	X	X	X	X	M	t	ζ_{pq}	X
1 2	3	7	11	15	19	23	27	31	35	39	43	53	63 72

30	9999	End Card

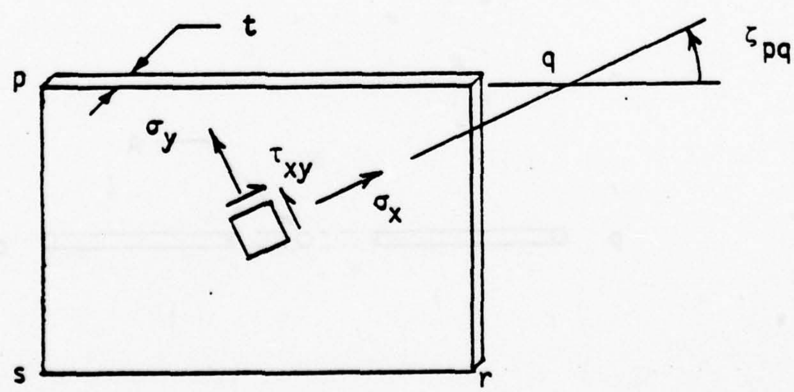
N = membrane identification number

p, q, r, s = joint numbers defining the four corners of the membrane, see below

M = material identification number (references code 10 data)

t = thickness of membrane

ζ_{pq} = stress orientation angle in degrees



Data Code 40, Cell Element Definition

User inputs one card for each cell and one end card. See pages 5 through 10 for discussion of finite elements.

RIGHT ADJUSTED INTEGER DATA											FLOATING POINT DATA		
40	N	p_o	q_o	r_o	s_o	p_1	q_1	r_1	s_1	M		ζ_{pq}	
1 2	3	7	11	15	19	23	27	31	35	39	43	53	63 72

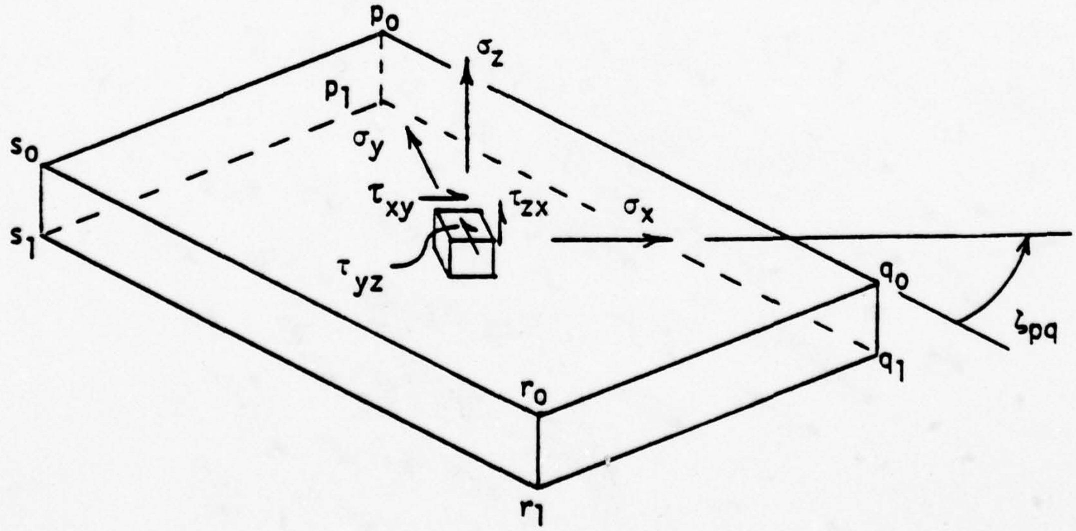
40	9999	End Card

N = cell identification number

p_o, q_o, r_o, s_o, p_1, q_1, r_1, s_1 = joint numbers defining the eight corners of the cell, see below

M = material reference number (code 10 data)

ζ_{pq} = stress orientation angle in degrees



Data Code 50, Point Mass Element Definition

User inputs one card for each point mass and one end card. See page 10 for discussion.

RIGHT ADJUSTED INTEGER DATA											FLOATING POINT DATA		
50	N	p									M_{pZ}	M_{pY}	M_{pZ}
1 2	3	7	11	15	19	23	27	31	35	39	43	53	63 72

50	9999	End Card

N = point mass identification number

p = joint number defining the location of the point mass

M_{pX}, M_{pY}, M_{pZ} = uncoupled mass contributions which will be added to the diagonal of the structural mass matrix in the X, Y, Z degrees of freedom at joint p

FORMAT Phase 2 Data

Three data deck setups are required as indicated in Figure 10. It is not necessary for the user to refer to the FORMAT documentation to use these setups. In keypunching the cards, it is important to begin in the card columns shown. Cards beginning with the $ character in CC1 have a control card name field in CC2-15 and an option field in CC16-72. The control card name and the optional information must be entered left justified in these fields as shown. All other cards in the sequence must begin in card column 7 and may be punched in free form. An exception is matrix data which has the following card format.

Header Card (one required for each matrix)

H	i_{max}	j_{max}		Name
1	2 - 5	6 - 9		67- 72

Data Card (use as many as required to input non-zero elements of matrix)

	i	j	Value	Exp	i	j	Value	Exp	i	j	Value	Exp	Name
1	2 - 5	6 - 9	11-19	20-22	24-27	28-31	33-41	42-44	46-49	50-53	55-63	64-66	67- 72

End of Matrix Data Card (one required)

E	
1	

Notes:
1. "Value" is of the form ±XXX.XX, plus sign may be omitted.
2. "Exp" is of the form ±XX, "Exp" = ±00 may be omitted.
3. More than one matrix may be input, but only one "E" card is required after the last matrix.

The following definitions apply.

i_{max}, j_{max}	=	row and column dimensions of the matrix
Name	=	one to six character alphameric matrix name assigned by the user. The first character must be alphabetical. Enter free form.
i, j	=	right adjusted integer values specifying the row and column location of a matrix element whose value is given in the next field
Value, Exp	=	value of the i, j matrix element

FORMAT Deck Setup 1

Card No.	Card Column 1 7 16
1	`$FØRMAT        STANDARD`
2	`$RUN           GØ,LØGIC`
3	`      INPUT TAPE (MTAPE,1)`
4	`      INPUT TAPE (LTAPE,1)`
5	`      OUTPUT TAPE (DECØMP,1)`
6	`      SIZE(NWØRK,KØNST)`
7	`$INSTRUCTION`
8	`      PT,DPT = DPØT ·DEJCØL· (1)`
9	`      SAVE(DECØMP)DPØT`
10	`      MR     = PRUF,MEL ·SEQWF·`
11	`      PRUPJ,PRUPS = PRUPT ·DEJCOL· (3n_J)`
12	`      PR     = PRUPJ ·MULT· PT`
13	`      PRT    = PR ·TRANSP·`
14	`      X,LTL,UR = PRUF,KEL ·SEQWF· PRT`
15	`      UT     = PRUP  ·TMULT· UR`
16	`      SAVE(DECØMP)MR,PRUPJ,LTL,UR`
17	`      PRINT(,,,)UT`
18	`$END`

An alternate setup after card 17 which will accommodate user input matrices on cards is:

```
$MATRIX        LIST
Card input matrix data, see pages 65 and 66 for card formats.
$END
```

In card 6 NWØRK represents words of working core storage, and KØNST is the maximum matrix dimension allowed. Default values are 10000 and 2000. Estimates can be calculated from equations 12 and 13, where w is the wave front, see "Joint Numbering" on page 28, and n_{PF} is given by equation 22.

In card 11, $3n_J$ = 3 x number of joints in the model.

$$\text{NWORK} \geq w^2/2 \qquad (12)$$

$$\text{KONST} \geq n_{PF} \qquad (13)$$

FORMAT Deck Setup 2

Card No.	Card Column 1 7 16
1	$FØRMAT STANDARD
2	$RUN GØ,LØGIC
3	INPUT TAPE (MTAPE,1)
4	INPUT TAPE (DECØMP,1)
5	ØUTPUT TAPE (TRANSF,1)
6	SIZE(NWØRK,KØNST)
7	$INSTRUCTIØN
8	VAL,TR = MR ·USER06· LTL
9	PRINT(,,,)VAL
10	PBUPJ = TR ·TMULT· PRUPJ
11	PBUF = TR ·TMULT· PRUF
12	DPBØ = PBUPJ ·MULT· DPØT
13	SAVE(TRANSF)TR,PBUPJ,PBUF,DPBØ
14	MØDES = PRUPJ ·TMULT· TR
15	PRINT(,,F2,.05)MØDES
16	$SPECIAL
	CC6 CC12 CC24 (Rt. adj. to noted CC)
17	n_G n_G 1.0E-6
18	$END

In card 15, the value .05 is a print cutoff which provides that any matrix element whose value is $\leq$ .05 will not be printed. The user may change the cutoff value if desired. If the value is zero or blank, all matrix elements will be printed except those whose value is zero.

In card 17, n_G is the number of modes to be used in the modal transformation. The modes extracted will correspond to the n_G lowest natural frequencies of the structure. The value 1.0E-6 is the convergence criterion for the eigenvalue calculation and is based on current experience levels.

FORMAT Deck Setup 3

Card No.	Card Column 1	7	16
1	$FORMAT		STANDARD
2	$RUN		GØ,LØGIC
3		INPUT TAPE (MTAPE,1)	
4		INPUT TAPE (TRANSF,1)	
5		OUTPUT TAPE (FILE20,1)	
6		OUTPUT TAPE (FILE21,1)	
7		SIZE(NWØRK,KØNST)	
8	$INSTRUCTION		
9		SAVE(FILE20)PBUF	
10		SAVE(FILE20)MPT	
11		SAVE(FILE20)UZERØ	
12		SAVE(FILE20)ECT,MEL,KBEL,CBEL,FFBAR	
13		SAVE(FILE20)SIGFB,EPSIG,DEBT,EVT,CØNST	
14		SAVE(FILE21)DPBØ	
15		SAVE(FILE21)PBUPJ	
16	$END		

<u>Incremental Response Data</u>

Card input to the Incremental Solution program consists of one card to specify options and dimensional quantities followed by one or more cards as needed to specify the time points which mark the end of each increment.

Card 1 (card columns 1 through 37 are used)

RIGHT ADJUSTED INTEGER DATA						
β	n_{EL}	n_β	n_G	T OR F	n_J	JWØRK
1 - 6	7 - 12	13 - 18	19 - 24	25	26 - 31	32 - 37

β = starting increment number

= 1

n_{EL} = total number of elements in the model including bars, membranes, cells, point mass.

n_β = number of increments in the solution

n_G = number of transformation modes

T, F = true, false, T means that element temperature changes will be calculated as a result of damping energy converted to heat. F means that they will not be calculated.

n_J = total number of joints in the model.

JWØRK = size of core work space required and must satisfy the following:

$$\text{JWØRK} \geq 1200 + 10.5\, n_G^2 + 29.5\, n_G + n_{EL} + n_\beta + 3\, n_J$$

$$\text{JWØRK} \geq 7000 + 2.5\, n_G^2 + 115.5\, n_G + n_{EL} + n_\beta + 4\, n_J$$

Card(s) 2 (card columns 1 through 72 are used)

FLOATING POINT DATA					
t_1	t_2	.	.	t_β	
1 - 12	13 - 24	25 - 36	37 - 48	49 - 60	61 - 72

t_β = time from beginning of impact (t_0) to the end of the βth increment, $\beta = 1,2,3,\ldots,n_\beta$. The t_β are the time points at which response solutions are calculated.

The t_β must be input in sequence at the rate of six values per card until n_β values have been entered.

Postprocessor Data

Card input to the Postprocessor program consists of six option definition cards, four title cards, and a variable number of selectivity cards.

Card Format for Cards 1 through 6

RIGHT ADJUSTED INTEGER DATA								FLOATING POINT	RIGHT ADJUSTED
a		b	c	d	e	f		g	h
1 2	3 - 10	11	12	13	14	15	16 - 20	21 - 30	31 - 40

INTEGER DATA			
i	j	k	
41 - 50	51 - 60	61 - 70	71 - 80

Card 1. Selectivity Options

a = 1

b = 0 or 1. "Zero" means that the user desires printout for all time increments. "One" means that the user will specify selected time increments for which he desires printout.

c = 0 or 1. "Zero" means that the user desires printout for all joints as dictated by card 2. "One" means that the user will specify selected joints for which he desires printout.

d = 0 or 1. "Zero" means that the user desires printout for all bars as dictated by card 4. "One" means he will specify selected bars.

e = 0 or 1. "Zero" means that the user desires printout for all membranes as dictated by card 5. "One" means he will specify selected membranes.

f = 0 or 1. "Zero" means that the user desires printout for all cells as dictated by card 6. "One" means he will specify selected cells.

g = value which the program will use to scale the joint displacements. May be useful when plotting the deformed structure joint coordinates. If this field is blank, the default value for the scalar is 1.0. The value is determined by experience.

h = KWØRK, which is the size of work space. The default is 10000. $10000 \leq KWØRK \geq 640 + L_1 + L_2 + 2n_\beta + 3n_j + 3n_G$.

where $6n_G \leq L_1 \geq 60$ and L_2 is the larger of the numbers of joints, bars, membranes or cells.

i = KLNMAX, which is the maximum number of lines per page, measured from the top of the page. The minimum value is 20, and a blank field results in a default value of 60.

j = KCLMAX, which is the number of elements across the page. The minimum value is 1, and a blank field results in a default (maximum) value of 8.

k = IFLGPR, a non-blank field sets a checkout print flag for intermediate print--normally not turned on by the user.

Card 2. Joint Data Options

a = 2

b,c,d,e are individually set equal to 0 or 1 to control printing of joint coordinates, displacements, velocities, and accelerations, respectively. "Zero" means no print. "One" means print.

f through k are not used.

Card 3. Modal Response Options

a = 3

b,c,d are individaully set equal to 0 or 1 to control printing of modal displacements, velocities and accelerations, respectively. "Zero" means no print. "One" means print.

e through k are not used.

Cards 4, 5, 6. Element Data Options

a = 4 for bar elements.
= 5 for membrane elements.
= 6 for cell elements

b,c,d,e are individually set equal to 0 or 1 to control printing of element forces, stresses, strains, and equivalent stresses, respectively. "Zero" means no print. "One" means print.

f through k are not used.

Card format for cards 7, 8, 9 and 10.

RT ADJ INTEGER			ALPHAMERIC
a			b
1	2	3 - 10	11 - 72

These four cards allow the user to specify two 120 character lines of title information to be printed at the top of each page of printout.

a = 7, b = characters 1-62 of first title line.
a = 8, b = characters 63-124 of first title line.
a = 9, b = characters 1-62 of second title line.
a = 10, b - characters 63-124 of second title line.

Card format for selectivity cards.

RIGHT ADJUSTED INTEGER DATA								
a		b		C_1	C_2	..	C_{11}	C_{12}
1	2	3 - 6	7 - 10	11-15	16 - 20		61 - 65	66 - 70

12 fields @ 5 cc each

Increment selections--required only when card 1 has a value of 1 in column 11.

a = 20

c_i = list of time increment numbers β for which printout is desired. Use additional cards as necessary.

b = 9999 in the last card.

Joint selections--required only when card 1 has a value of 1 in column 12.

a = 30

c_i = list of joint numbers for which printout is desired. Use additional cards as necessary.

b = 9999 in the last card.

Bar selections--required only when card 1 has a value of 1 in column 13.

a = 40

c_i = list of bar numbers for which printout is desired. Use additional cards as necessary.

b = 9999 in the last card.

Membrane selections--required only when card 1 has a value of 1 in column 14.

a = 50

c_i = list of membrane numbers for which printout is desired. Use additional cards as necessary.

b = 9999 in the last card.

Cell selections--required only when card 1 has a value of 1 in column 15.

a = 60

c_i = list of cell numbers for which printout is desired. Use additional cards as necessary.

b = 9999 in the last card.

In any of the selectivity cards described above, an inclusive range of numbers may be specified by entering the lower and upper bounding numbers with a non-blank character (such as—) entered between them in the first card column of the field containing the upper bounding number.

Job Control Language (JCL)

The Programming Manual, which is Part 3 (a separate volume) of this report, describes program implemenation procedure at a given computer installation and the job control language (JCL) required to execute the IMPACT computer programs. The JCL deck contains estimates of computer time, core, and other resource requirements for the job, manipulates input and output data files, and calls and executes program load modules. A JCL deck together with the appropriate input data cards must be set up and loaded into the computer to perform the functions shown in Figure 10. Depending on the size of the finite element model being analyzed, the JCL setup may be tailored to perform each function as an individual computer run in the case of a large model or to perform all functions in one computer run for small models. Reference Appendix A for additional information and examples of JCL.

INPUT PREPROCESSING

Input preprocessing includes the input and editing of model definition decks by means of the CDC UPDATE procedure, the generation of additional model definition data using the Laminate Generator, and the generation of the bird impact incremental loads matrix using the Loads Generator program. The makeup of the model definition deck is discussed under Data Code Descriptions in the previous subsection. UPDATE is a CDC system module for creating, accessing and editing data files and is utilized through appropriate JCL.

Laminate Generator

The use of the Laminate Generator program is not manditory, but it is intended to relieve the user of much of the effort required to pre-

pare model definition data for the transparency, especially when it is a multi-layered laminate having compound curvature.

General Description

In order to take advantage of the Laminate Generator capability the transparency must be modelled entirely of cell elements. Minimum required input data includes data code 2 joint coordinates of the joints in the surface of the transparency, data code 7 laminate definition cards and data code 40 cards giving the cell identification number and the first four corner joint numbers for each cell in the surface layer of the transparency. The program then calculates joint coordinates for all additional joints required to define the transparency geometry and produces cell definition data to complete surface cell definitions and to define all additional cell elements needed to form sublayers of the transparency.

Consider a 5-layered laminated transparency modelled with a 10 x 10 surface grid. Such a model would have 600 joints and 405 cell elements. The user would input joint coordinates for 100 surface joints, partial cell definitons for 81 cells in the surface layer, and information specifying thicknesses and materials of layers and numbering of joints and cells. The program will produce the completed data code 2 deck for 600 joints, a data code 6 deck defining unit vectors normal to the surface at the 100 surface joints, and a completed data code 40 deck defining the 405 cell elements.

The input file is Fortran logical unit 1 and is passed to the Laminate Generator from an UPDATE data file, as indicated in Figure 10. Table 4 shows optional data code decks which may be present in the input file as well as the minimum required input discussed above. If the optional input is present, it will be duplicated (except data codes 7 and 8) in the output file, thus creating a complete model definition deck. This completed model definition deck is now in the form required

for use in the Loads or Initial Generators. If the optional input is not present, the Laminate Generator output data file will have to be merged with other data files as appropriate to form a complete model definition file. The output file is Fortran logical unit 2 and is copied to an UPDATE data file and saved for future use or it may be copied to appropriate Fortran logical units and passed directly to the Loads or Initial Generators.

The Laminate Generator unconditionally prints out a listing of all data code decks present in the output file.

Definitions and Use Details

Figure 11 shows a representative portion of a finite element model for a 3-layered laminate and support structure. The following definitions apply.

1) Surface normal--a unit vector directed into the laminate based on the average of cross products of surface element edge vectors emanating from a surface joint.

2) Joint stack--a set of joints including a surface joint and all joints through the laminate to the opposite surface, reference Figure 11 (1,2,3,4), (13,14,15,16), etc. The joint stack line is usually parallel to the surface normal as defined above.

3) Layer thicknesses--thickness t_ℓ input by the user for each layer ℓ and used by the program together with normal vectors and surface joint coordinates to calculate the coordinates of all other joints in each stack.

4) Joint numbering increment--an integer value ΔJ_ℓ input by the user for each layer ℓ and used by the program to assign joint numbers in the joint stacks starting from the user assigned surface joint number and proceeding through the stack. In Figure 11, $\Delta J_\ell = 1$ for all layers. The value for ΔJ_ℓ cannot be negative.

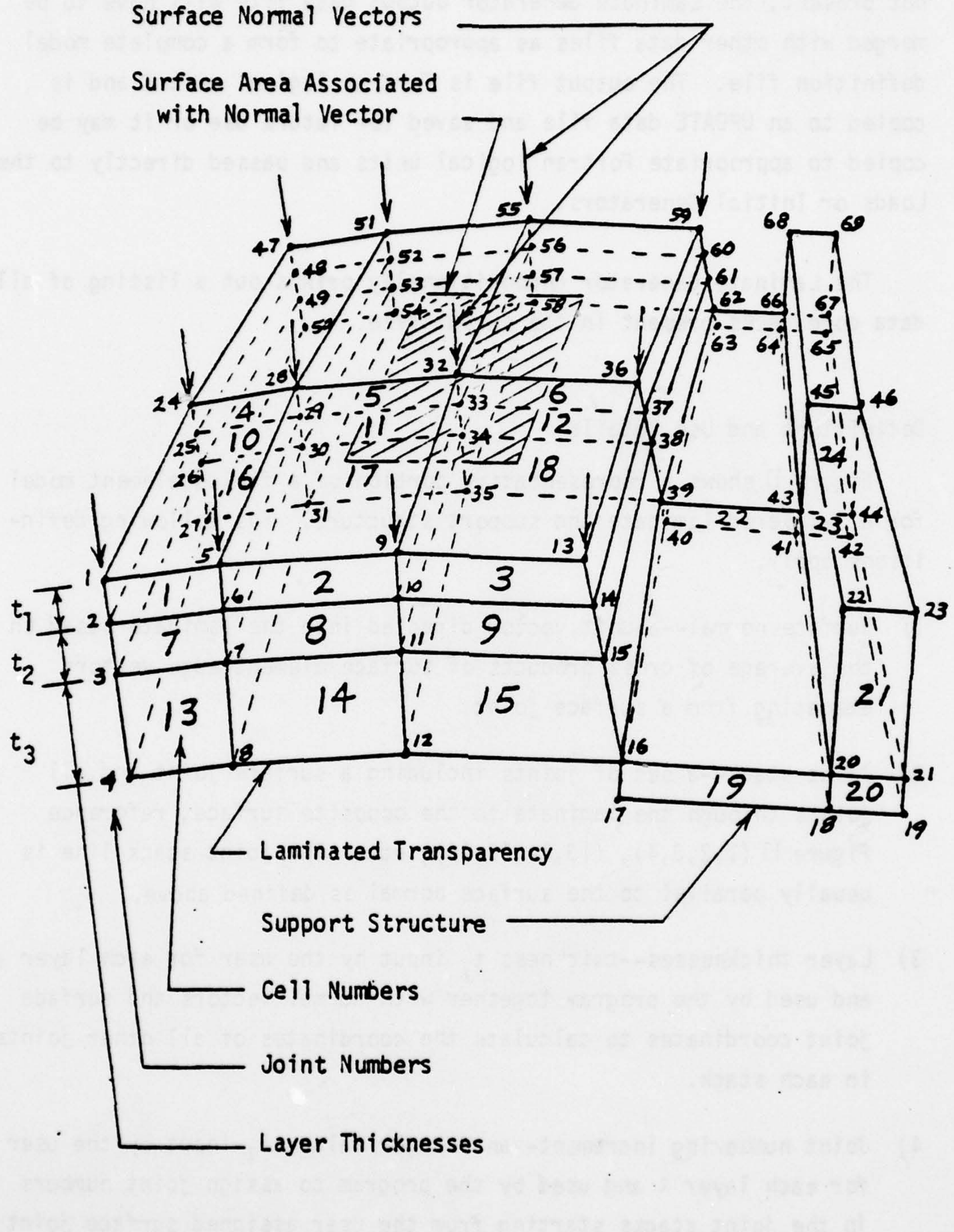


Figure 11. Simple Model of Laminate and Support Structure.

5) Element stack--a set of cell elements including a surface layer cell and a cell for each additional layer in the laminate, reference Figure 11, (1,7,13), (6,12,18), etc.

6) Element numbering increment--an integer value ΔE_ℓ input by the user for each layer ℓ and used by the program to assign element numbers in the joint stacks starting from the user assigned surface element number and proceeding through the stack. In Figure 11, $\Delta E_\ell = 6$ for all layers. The value for ΔE_ℓ cannot be negative.

7) Surface offset--a distance t_0 input by the user and used by the program to calculate new surface joint coordinates such that the entire surface is moved a constant distance t_0 outward or inward from its original position (positive t_0 results in offset opposite to the unit normal vector directions).

8) Partial cell element definitions--a code 40 card input by the user having the cell identification number, the first four corner joint numbers, and the stress orientation angle (if applicable) entered in their appropriate fields. Note that the corner joint numbers must be surface joints and they must be entered in a clockwise sequence looking down on the surface in the direction of the unit vectors. In Figure 11 for cell number 1 the sequence could be one of four choices: (1,24,28,5), (24,28,5,1), (28,5,1,24) or (5,1,24,28).

9) Variable layer thicknesses-thickness t_ℓ input by the user for each layer ℓ at each surface joint as necessary to define a realistic variation in layer thickness.

Items defined in 3, 4, 6 and 7 above are input on data code 7 cards together with a material reference for each layer. The variable thickness data defined in 9 is input on data code 8 cards.

As mentioned in 2 above, the joint stack line will be parallel to

the surface normal vector if only the laminate surface joint coordinates are input. However, the user may control the direction of the stack line by inputting coordinates for the last joint in the stack as well as the surface joint. In fact, intermediate joint coordinates may also be input if desired. In Figure 11 this is illustrated along the edge of the laminate which is attached to the support structure at joints 16, 39 and 62. User input of coordinates for these joints controls the stack line direction to insure that the attach line between the laminate and the support structure will be where the user wants it. The undesirable alternative would be to adjust coordinates of surface joints 13, 36 and 59 to force the surface normals to intersect the desired attach line.

The Laminate Generator discussion is summarized by again referring to Figure 11. For this model the user should input data code 2 coordinates for laminate surface joints 1, 5, 9, 13, 24, 28, 32, 36, 47, 51, 55 and 59 and for support structure joints 16-23, 39-46, and 62-69. He should input data code 7 to define surface offset (if necessary), layer material, joint and element numbering increments, and thickness for each of the three layers. Data code 8 cards should be input if there are variations in thickness of the layers. Finally, data code 40 cards should be input to partially define surface elements 1-6 and completely define elements 19-24. Optional data codes, 1, 3, 4, 5, 10, 11, 12, 20, 30, 40, and 50 should be included if available. Now, execution of the Laminate Generator program will result in a completed data code 2 deck with missing joint coordinates inserted, a new data code 6 deck of surface normal vectors and associated surface areas, and a completed data code 40 deck with all missing element definition data inserted. In addition, all optional data code decks which were present in the input file will have been output in proper sequence. Data codes 7 and 8 which are used by the Laminate Generator are excluded from the output.

Loads Generator

The problem of determining a space/time distribution of applied loads at the model joints which accurately represents bird impact phenomena is a very difficult one. Reference 2 reports on experimental and analytical investigations of bird impact, presents some practical formulations of force/time distribution as well as pressure distributions within the impact footprint, and makes recommendations for the continuation of this important work.

General Description

The Loads Generator program is an elementary capability which calculates the average impact force using the formulation of Reference 2, allows the user to specify the force/time distribution and the movement of the footprint, and calculates the resulting load components on joints within the footprint. The load distribution to the joints is not based on impact pressures but instead is based on the method of Lagrangian multipliers to solve equilibrium equations relating joint loads to the resultant impact force. Target compliance is not accounted for, but a travelling footprint can be accommodated.

The input file is Fortran logical unit 1 and is passed to the Loads Generator from an UPDATE data file, as indicated in Figure 10. Data code decks required to be present in the input file are shown in Table 4. Optional data codes present in the input will be read over and ignored. The output file is Fortran logical unit 3 and contains the incremental loads matrix stored in the form of a FØRMAT matrix tape named LTAPE,1. It may be copied either to the appropriate Fortran logical unit for input to a FØRMAT step or to tape and saved for future use. Alternately, the output file which is also stored in card image form on Fortran logical unit 2 may be punched on cards in a form suitable for matrix card input to the FØRMAT step. These options are exercised by means of JCL cards.

The Loads Generator unconditionally prints a load summary for each time increment during the impact. The summary includes the load (time) increment number, bird mass and velocity, duration of impact and average impact force, direction and magnitude of the resultant impact force for the given increment, the loaded joint numbers together with their total loads for the given increment and their incremental load changes from the previous increment, and finally a column of the output incremental loads matrix.

Definitions and Use Details

Figure 12 shows parameters and diagrams which the user must consider in order to prepare input data for the Loads Generator. The following definitions apply.

1) $3n_J$ -- row dimension of incremental loads matrix

2) m -- bird mass

3) v -- bird velocity

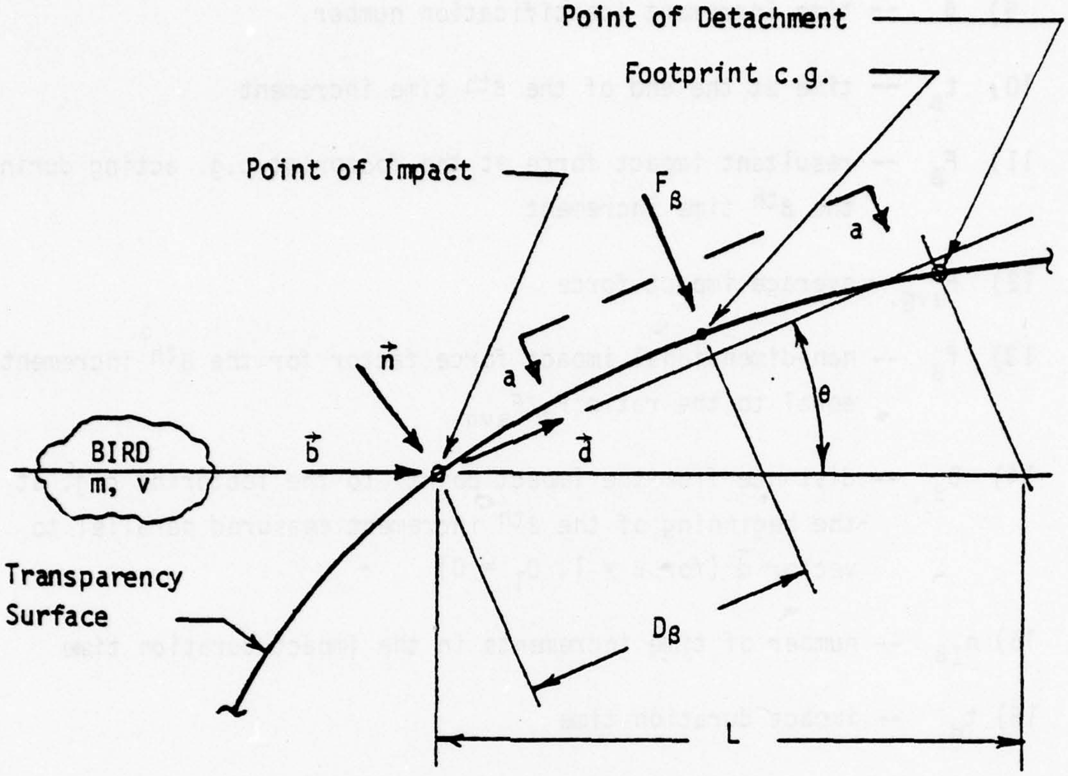
4) L -- estimated total travel of footprint along $\vec{d}$ from point of impact to point of detachment divided by cosine θ

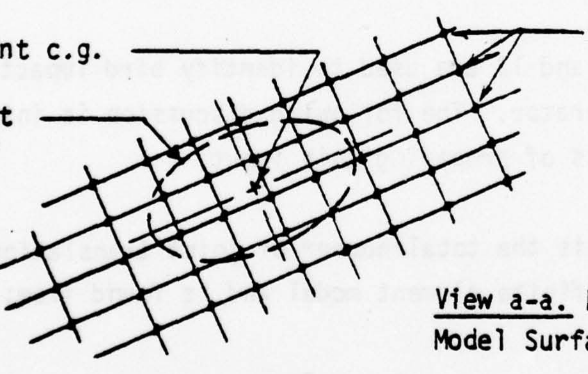
5) θ -- angle through which the bird material is expected to be deflected during the impact

6) $\vec{b}$ -- unit vector parallel to bird path prior to impact

7) $\vec{n}$ -- unit vector normal to transparency surface at impact point

8) $\vec{d}$ -- unit vector in plane with vectors $\vec{b}$ and $\vec{n}$ and making the angle θ with vector $\vec{b}$





View a-a. Finite Element Model Surface Grid

Figure 12. Bird Impact Diagram.

9) β -- time increment identification number

10) t_β -- time at the end of the β^{th} time increment

11) F_β -- resultant impact force at the footprint c.g. acting during the β^{th} time increment

12) F_{avg} -- average impact force

13) f_β -- non-dimensional impact force factor for the β^{th} increment equal to the ratio F_β/F_{avg}

14) D_β -- distance from the impact point to the footprint c.g. at the beginning of the β^{th} increment measured parallel to vector $\vec{d}$ (for $\beta = 1$, $D_1 = 0$)

15) $n_{I\beta}$ -- number of time increments in the impact duration time

16) t_d -- impact duration time

17) X_o, Y_o, Z_o -- coordinates of the impact point

Data codes 11 and 12 are used to identify bird impact input data for the Loads Generator. The following discussion is intended to clarify the details of preparing this input.

The value n_{TJ} is the total number of joint translational degrees of freedom in the finite element model and is found from:

$$n_{TJ} = 3n_J \tag{14}$$

where n_J is the total number of joints in the model.

Bird mass m and velocity v are specified by the user in order to produce the desired impact. It should be recognized that v is the relative velocity of bird to transparency.

The value of L is an important parameter because it determines the impact duration time. It should be estimated based on the user's experience and best judgement for each impact case. Reference 2 defines L as the length of the bird in the case of a rigid target whose surface is normal to the bird path, and gives a modified effective length in the case of inclined surfaces. The travelling footprint concept described here is a further modification.

At this point the user must establish the number of impact increments $n_{I\beta}$ and the time points t_β marking the end of each increment. Figure 13 is a nondimensional representation of the triangular impact force/time distribution as derived in Reference 2. It shows the impact divided into ten equal increments and gives the values of the force factor f_β. It is not necessary that the increments be equal. The values for $n_{I\beta}$, t_β and f_β should be determined in as much detail as necessary to reasonably represent the desired force/time distribution, whether it be triangular or some other shape. For example, the dotted line in Figure 13 represents a trapezoidal distribution that may be more applicable for the compliant target and travelling footprint. The value of t_d is needed to determine the actual values of t_β.

$$t_d = \frac{L}{V} \tag{15}$$

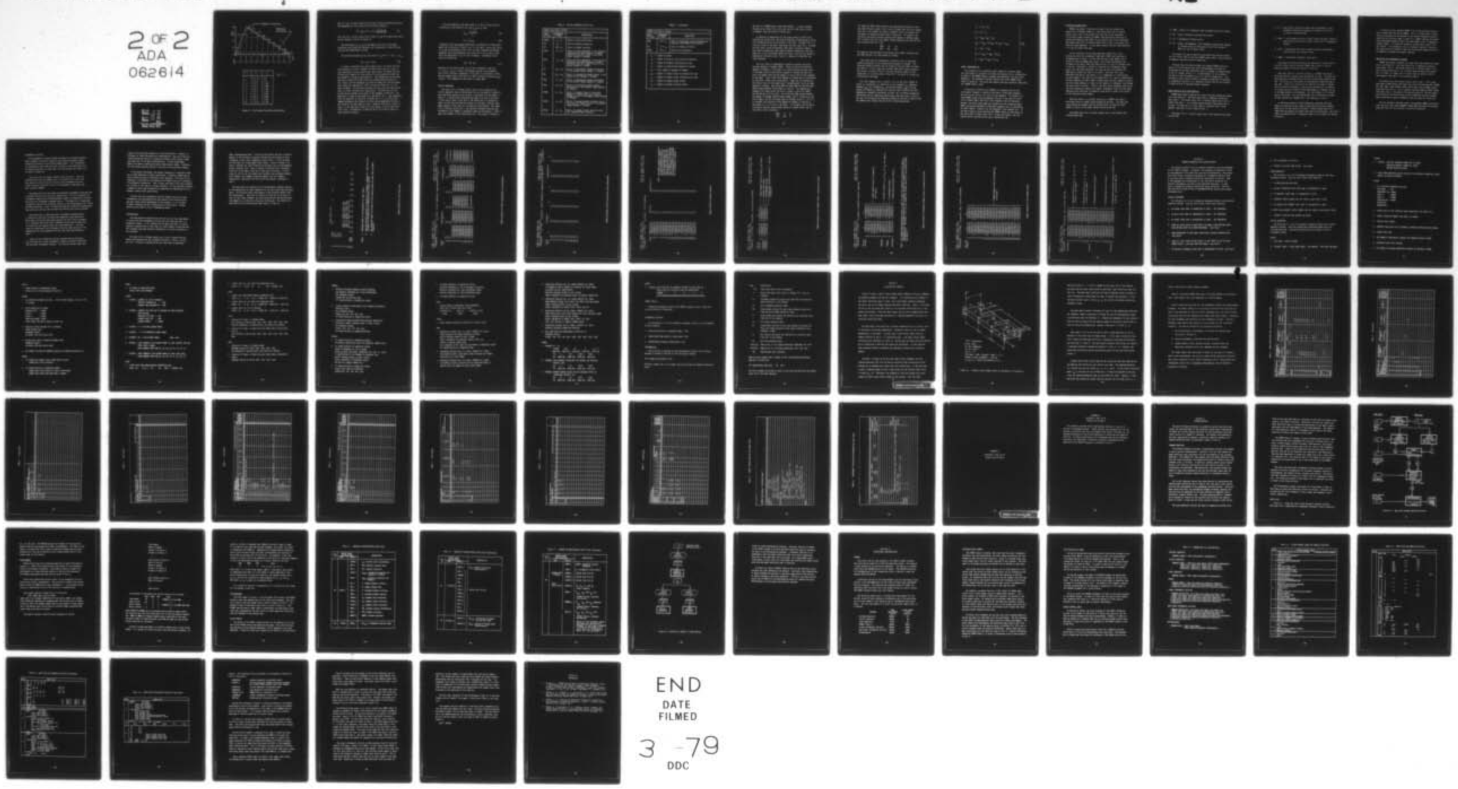
To insure that the correct total impulse is being input to the Loads Generator the user should check that the following equation is satisfied ($\beta = 1,2,3,\ldots,n_{I\beta}$).

$$\sum f_\beta(t_\beta - t_{\beta-1}) = t_d \tag{16}$$

The unit vector $\vec{b}$, $\vec{n}$ and $\vec{d}$ are input in terms of their x, y, z components in the model coordinate axes system. The user must calculate the components of $\vec{b}$ consistent with the desired bird path. The components of $\vec{n}$ can be determined from the data code 6 surface normals for the joints nearest to the point of impact. The data code 6 infor-

AD-A062 614 DOUGLAS AIRCRAFT CO LONG BEACH CALIF F/G 5/2
AIRCRAFT WINDSHIELD BIRD IMPACT MATH MODEL. PART 2. USER'S MANU--ETC(U)
DEC 77 G R EIDE F33615-75-C-3105
UNCLASSIFIED MDC-J7174-PT-2 AFFDL-TR-77-99-PT-2 NL

2 OF 2
ADA
062614



END
DATE
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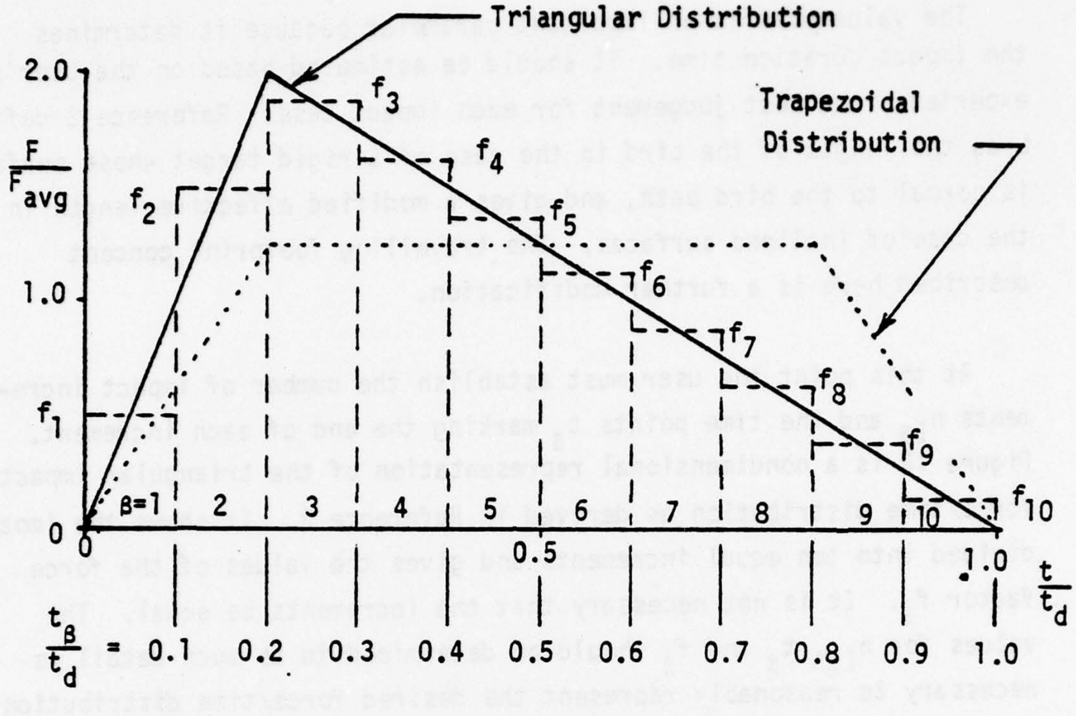
DDC



β	t_β	f_β
1	0.1 t_d	0.5
2	0.2	1.5
3	0.3	1.875
4	0.4	1.625
5	0.5	1.375
6	0.6	1.125
7	0.7	0.875
8	0.8	0.625
9	0.9	0.375
10	1.0 t_d	0.125

$n_{I\beta} = 10$

Figure 13. Bird Impact Force/Time Distribution.

mation is part of the unconditional printout from the Laminate Generator. The components of $\vec{d}$ are given by the following equation.

$$\vec{d} = (\cos\theta)\,\vec{b} - (\sin\theta)\,\frac{\vec{b} \times \vec{n} \times \vec{b}}{|\vec{b} \times \vec{n} \times \vec{b}|} \qquad (17)$$

The value for θ can be scaled from a layout of the bird impact and transparency geometry similar to Figure 12.

The coordinates X_o, Y_o, Z_o of the impact point are in the model coordinate axes system and represent the intersection of the bird path line and the transparency surface.

The following equation gives the values of D_β for $\beta = 1,2,3,\ldots,n_{I\beta}$.

$$D_\beta = t_{\beta-1}\, v \cos\theta \qquad (18)$$

In order to determine the joint numbers which lie within the footprint boundary for each increment the user should lay out a view of the transparency surface showing the impact point, the model grid and surface joint numbers for that portion of the surface over which the bird material will pass, see Figure 12. The intersection of the plane containing vectors $\vec{b}$, $\vec{n}$ and $\vec{d}$ with the surface should be drawn on the layout, and the distances D_β should be marked off from the impact point along the intersection line to locate the footprint c.g. for each increment. The footprint boundary ellipse should be drawn around each c.g. point including the impact point. The minor axis of the ellipse may be assumed to be equal to the diameter of the bird. The major axis is equal to the minor axis divided by sin θ. Now, beginning with the footprint at the point of impact for $\beta = 1$, a set of joint numbers bounded by the footprint ellipse can be determined for each β and listed on the data code 12 cards. Footprint overlap is likely to occur, so the same joint number will then appear in two or more footprint lists. Nevertheless, a complete joint list must be input for each footprint location.

The Loads Generator uses data codes 2, 11 and 12 input data and calculates t_d from Equation (15) and F_{avg} and F_β from

$$F_{avg} = \frac{m\ v\ \sin\theta}{t_d} \tag{19}$$

$$F_\beta = f_\beta\ F_{avg} \tag{20}$$

In Equation (19) the program effectively calculates sin θ from vector operations involving $\vec{b}$, $\vec{n}$ and $\vec{d}$, so θ is not input. Having the values of F_β and the associated joint lists for each increment the program generates equilibrium equations and solves for a set of joint loads which are equivalent to F_β for each increment. Incremental joint loads are found from

$$\delta\Phi_\beta = \Phi_\beta - \Phi_{\beta-1} \tag{21}$$

where Φ_β are the joint loads, $\delta\Phi_\beta$ are the incremental loads and $\beta = 1,2,3,\ldots,n_{I\beta}+1$. Finally the program converts the incremental joint loads into their components in the joint X,Y,Z degrees of freedom and outputs them in the form of a matrix having $3n_J$ rows and $n_{I\beta}+1$ columns. The incremental loads matrix is named DPØT.

INITIAL GENERATOR

The input file is Fortran logical unit 5 and is passed to the Initial Generator from an UPDATE data file, as indicated in Figure 10. Data code decks required to be present in the input file are shown in Table 4. A required data code deck may consist of only an end card if that type of data is not used in the definition of a particular model, but the end card must be present as a minimum. Optional data codes present in the input will be read over and ignored. The output file is Fortran logical unit 1 and contains structural matrices and information lists needed in subsequent steps of the analysis. Table 6 shows the contents of the output data file. The output is stored in

TABLE 6. INITIAL GENERATOR OUTPUT FILE

FØRMAT Tape Name Is MTAPE,1

NAME OF ARRAY	DIMENSIONS OF ARRAY	DESCRIPTION
UZERØ	$n_J \times 3$	Matrix of joint coordinates.
MPT	$n_m \times 1$	Table of material properties.
ECT	$100 \times n_e$	Table of element constants.
PRUPT	$n_u \times n_T$	Matrix of force components in the reordered unconstrained global degrees of freedom resulting from unit forces in the total global degrees of freedom.
PRUF	$n_u \times n_{PF}$	Matrix of force components in the reordered unconstrained global degrees of freedom resulting from unit element forces in the global degrees of freedom.
KEL	$n_{PF} \times n_{PF}$	Matrix of unassembled element stiffnesses in the element global degrees of freedom.
MEL	$n_{PF} \times n_{PF}$	Matrix of unassembled element masses in the element global degrees of freedom.
KBEL	$n_{\bar{F}} \times n_{\bar{F}}$	Matrix of unassembled element stiffnesses in the element lumped degrees of freedom.
CBEL	$n_{\bar{F}} \times n_{\bar{F}}$	Matrix of unassembled element damping sub-matrices in the element lumped degrees of freedom.
FFBAR	$n_F \times n_{\bar{F}}$	Matrix of element forces in the global degrees of freedom resulting from unit element forces in the element lumped degrees of freedom.
SIGFB	$n_S \times n_{\bar{F}}$	Matrix of average element stresses resulting from unit element forces in the element lumped degrees of freedom.
EPSIG	$n_S \times n_S$	Matrix of element strains resulting from unit average element stresses.

TABLE 6. (continued)

FORMAT Tape Name Is MTAPE,1		
NAME OF ARRAY	DIMENSIONS OF ARRAY	DESCRIPTION
DEBT	$30 \times n_e$	Table of unassembled element deformations resulting from temperature gradients.
EVT	$24 \times n_e$	Table of element variables.
CONST	30×1	Table of job constants.

n_J = number of joints

n_m = number of words to store material properties

n_e = number of elements excluding point mass

n_u = number of unconstrained degrees of freedom

n_T = total number of degrees of freedom

n_{PF} = number of element forces including point mass

n_F = number of element forces excluding point mass

$n_{\bar{F}}$ = number of lumped element forces

n_S = number of element stresses/strains

the form of a FØRMAT matrix tape named MTAPE,1. It can be passed directly as an input file to the next analysis step and/or copied to magnetic tape and saved for future use.

In addition to generating all the arrays shown in Table 6 and creating the output file, the Initial Generator unconditionally prints out information which may be helpful to the user. Printed first is a listing of some of the data code decks from the input file. Included are data code 2 joint coordinates, data code 4 direction numbers, data code 5 constraints, data code 10 material properties, and data codes 20, 30, 40, 50 element definition data. Next are two tables of bookkeeping information and, finally, a summary of dimensions and input constants.

The first table of bookkeeping information defines the unconstrained degrees of freedom (UDØF). There are three translational degrees of freedom in the global X,Y,Z axes directions at each joint in the model and one translational degree of freedom colinear with each line segment defining the edge(s) of one or more finite elements in the model. Some of the joint degrees of freedom may be constrained as specified in data code 5 constraints. Edges are not constrained. This table lists all the remaining or "unconstrained" joint and edge degrees of freedom. Both joint UDØF and edge UDØF are defined under three column headings titled UDØF, J1, and J2. The headings are repeated five times across the top of a page, so that five UDØF's are defined per line of print. For joints the UDØF column contains the degree of freedom identification number, the J1 column gives the joint number, and the J2 column shows an integer value of 1, 2, or 3 to indicate the direction of the degree of freedom is parallel to the global X, Y, or Z axis of the model. For example, the following information defines unconstrained degree of freedom number 1291 at joint 452 in the Y-direction.

UDØF	J1	J2
1291	452	2

For edges the UDØF column contains the unconstrained degree of freedom identification number, the J1 and J2 columns give two joint numbers defining a line segment (or edge of elements) which is colinear with the degree of freedom directed from J1 toward J2. For example, the following information defines unconstrained degree of freedom number 3011 colinear with the line segment (edge) between joints 164 and 168 and directed from 164 to 168.

UDØF	J1	J2
3011	164	-168

The negative sign attached to the second joint number indicates that the UDØF defined is an edge degree of freedom.

The second table of bookkeeping information gives a reordered numbering sequence for the unconstrained degrees of freedom. The reordered sequence defines the row format of matrices PRUPT and PRUF, see Table 6. In this table the original UDØF identification numbers are listed in columns titled "U" and the reordered numbers follow immediately in a second column titled "RU". Ten pairs of columns are printed across the page.

The final summary print is simply a list of the total numbers of joints n_J, constraints n_C, materials n_M, bar elements n_{Be}, membrane elements n_{Me}, cell elements n_{Ce}, point mass elements n_{Pe}, and edge degrees of freedom n_E together with constant data including the base temperature, mechanical equivalent of heat, cell stiffness suppression coefficient and bar compliance coefficients (see data code 1, card 2). The user can calculate the dimensions defined at the end of Table 6 from the summary data through the use of the following equations.

$$\left.\begin{aligned}
n_T &= 3\,n_J + n_E \\
n_u &= n_T - n_C \\
n_e &= n_{Be} + n_{Me} + n_{Ce} \\
n_{PF} &= 7\,n_{Be} + 16\,n_{Me} + 36\,n_{Ce} + 3\,n_{Pe} \\
n_F &= n_{PF} - 3\,n_{Pe} \\
n_{\bar{F}} &= 2\,n_{Be} + 9\,n_{Me} + 30\,n_{Ce} \\
n_S &= n_{Be} + 3\,n_{Me} + 12\,n_{Ce}
\end{aligned}\right\} \tag{22}$$

MODAL TRANSFORMATION

The extraction of a relatively small number of vibration modes and using them as a transform to reduce the problem size is accomplished by means of the FØRMAT Phase 2 program, see Reference 1 for user documentation. The procedure involves executing the three FØRMAT steps shown in Figure 10. The input deck setups have been previously described, see "FØRMAT Phase 2 Data".

A user who is familiar with FØRMAT will recognize that he has considerable freedom in setting up the matrix instruction sequence and that he can tailor it to suit his own purposes. For example, all three FØRMAT steps could be combined into one in the case of a small finite element model requiring little computer time and resources. However, the three steps shown are suitable for both large and small models and may be executed as individual computer runs, or optionally for small models, linked by JCL and executed in one computer run. If the user wishes to avoid handling the FØRMAT setups as card decks, he may store them in UPDATE data files. He may then access, edit and execute them as desired by the use of appropriate JCL.

Stiffness Decomposition

FØRMAT deck setup 1 requires two input files and creates one output file, reference Figure 10. The first input file is Fortran logical unit 2 and is the output file from the Initial Generator. It is either copied directly by FØRMAT from the Initial Generator or copied from magnetic tape where it was stored by the Initial Generator. The second input file is Fortran logical unit 3 and is the output file from the Loads Generator. It may come directly from the Loads Generator or it may be copied from tape.

In the discussion of the Loads Generator output file it was pointed out that the incremental loads matrix DPØT could optionally be punched out on cards. In that case the user could delete card 4 (LTAPE,1) from the FØRMAT deck setup 1, and insert the ØMATRIX card followed by the matrix DPØT card data and the "E" card all between cards 17 and 18. Alternately, instead of inputting the incremental loads matrix from the Loads Generator, the user may elect to generate the DPØT matrix himself and input it on cards. Note that for a user generated load matrix, the global X, Y, Z components of a load acting on joint number j are input in row numbers 3j-2, 3j-1 and 3j, respectively. The row dimension of matrix DPØT is three times the total number of joints and the column dimension is equal to the number of incremental load changes the user wishes to define. Finally, the user should recognize that he can use this approach to combine bird impact incremental loads from the Loads Generator with additional incremental loads which he knows to be acting on the structure during impact.

Note that there is a variable called $3n_j$ in FØRMAT deck setup 1 which must have an integer value assigned by the user. The data card involved must be updated with the correct value (3 times the total number of joints in the model) before executing the job.

The output data file is Fortran logical unit 4 and contains the following matrices.

1) DPØT -- matrix of incremental loads representing the bird impact

2) MR -- upper triangular structural mass matrix

3) LTL -- decomposed stiffness matrix

4) UR -- static displacements in the reordered unconstrained degrees of freedom resulting from applying the first column of DPØT as a set of static loads

The output file may be copied to the appropriate Fortran logical unit for direct input to the next FORMAT step, and/or it may be copied to magnetic tape and saved for future use.

Printout from this step includes the standard FORMAT print and matrix UT, which contains the static displacements of matrix UR transformed to the more convenient total (T) degree of freedom format. In the "T" format, global X, Y, Z displacements for joint number j are found in the row numbers 3j-2, 3j-1 and 3j, respectively. The printout of the UT matrix should be scanned to determine if the model is responding statically in a reasonable fashion and for any insights it might give as to expected dynamic response.

Mode Extraction and Transformation

FØRMAT deck setup 2 requires two input files and creates one output file, see Figure 10. The first input file is identical to that of deck setup 1. The second input file is Fortran logical unit 3 and is output from step 1. It is either copied directly from output unit 4 in step 1 to input unit 3 in this step, or copied to unit 3 from magnetic tape where it was stored by step 1.

The output file is Fortran logical unit 4 and contains the following matrices.

1) TR -- modes matrix containing normalized displacements in the reordered unconstrained degrees of freedom for the first n_G natural vibration modes

2) PBUPJ -- transformed partition of PRUPT containing model displacements resulting from unit forces in the joint "T" degrees of freedom

3) PBUF -- transformed PRUF matrix containing modal displacements resulting from unit element forces

4) DPBØ -- transformed incremental loads matrix

The output file may be copied to the appropriate Fortran logical unit for direct input to the next FØRMAT step, and/or it may be copied to magnetic tape and saved for future use.

Note that there is a variable called n_G in FORMAT deck setup 2 which must have an integer value assigned by the user. The data card involved must be updated with the correct value before executing the job. The value n_G is the number of transformation modes desired by the user. There is no fixed rule for choosing the number of modes, but for practical purposes $n_G \leq 50$ may be considered as a guideline. In linear analysis of models having 5000 degrees of freedom, the use of 30 modes appears to be adequate. For small models 5 or 10 modes may be sufficient. The core requirement can be considered the same as that required for decomposition, see equations 12 and 13.

In nonlinear analysis limited experience indicates that more modes are required and that some of them should be higher frequency modes which are not readily available. Suitable modes need to be identified and methods to extract them need to be developed. See "Part 1 Theory and Applications" (a separate volume of this report) for further discussion.

In addition to the standard FØRMAT listing the printout from this step includes matrices VAL and MØDES. VAL is a column matrix containing the reciprocals of the squares of the natural frequencies associated with the vibration modes in matrix TR. MØDES contains the normalized displacement modes of matrix TR transformed to the "T" degree of freedom format. To reduce the volume of printout only values ≥ .05 are printed. The frequencies may be of general interest to the user. The modes should be plotted as they are the deformed shapes which will be combined to produce the dynamic response.

Data Files for Incremental Solution

FORMAT deck setup 3 requires two input files and creates two output files, see Figure 10. The first input file is identical to that of deck setups 1 and 2. The second input file is Fortran logical unit 3 and is output from step 2. It is either copied directly from output unit 4 in step 2 to input unit 3 in this step, or copied to unit 3 from magnetic tape where it was stored by step 2.

The output files are Fortran logical units 4 and 7. Unit 4 contains matrix PBUF copied from input file unit 3 and matrices MPT, UZERØ, ECT, MEL, KBEL, CBEL, FFBAR, SIGFB, EPSIG, DEBT, EVT and CØNST copied from input file unit 2. Unit 7 contains matrices DPBØ and PBUPJ copied from input unit 3. The output files may be copied to Fortran logical units 20 and 21 for direct input to the Incremental Solution program, and/or they may be copied to magnetic tape and saved for future use.

The only printout from this step is the standard FØRMAT print which lists the user input cards $FØRMAT through $END and prints the program generated logic for the solution of the matrix equations.

INCREMENTAL SOLUTION

The Incremental Solution program calculates the transient dynamic modal response to the bird impact and the resulting element forces, stresses and strains in the finite element model. This information is calculated at each time point and is saved in the output data file. The program requires two input data files and creates one output file as shown in Figure 10.

The input files are Fortran logical units 20 and 21. They are generated and output by FØRMAT step 3 on logical units 4 and 7 and are copied to units 20 and 21 for use in the Incremental Solution either directly from units 4 and 7 or from magnetic tape where they were stored by FØRMAT.

The output files for the Linear and Nonlinear Incremental Solutions are on Fortran logical units 2 and 23, respectively. This file contains the information required by the Postprocessor program to selectively calculate and print the incremental response results. The output file is generated on magnetic tape and may be passed directly to the Postprocessor for initial printout selections. Also, it should be saved for additional Postprocessor runs which the user may want to make after seeing the initial printout.

Card input data is described under "Incremental Response Data". It consists of one card of option and dimensional data and one or more cards listing the time points marking the end of each increment. It is important that these time increments be the same as those used in calculating the impact loads, see "Loads Generator". The deck setup for execution of the Incremental Solution code consists of the appropriate JCL cards together with the card input data mentioned above.

There are two Incremental Solution program modules available. One calculates the linear incremental response; the other calculates the nonlinear incremental response. The user may attach either the

linear or the nonlinear program in a given application. However, as indicated in "Mode Extraction and Transformation", the use of the nonlinear program may result in unrealistic answers unless special modes have been used in the modal transformation. Further development needs to be done to define and extract these special modes. Therefore, the user should exercise caution in the use of the nonlinear program.

If continued long enough, the dynamic response will eventually damp out to some condition of static equilibrium. Therefore, IMPACT may be used to perform linear or nonlinear static analyses. This use will be expedited if arbitrarily high damping to stiffness ratios are introduced in the material properties. Then a single relatively long time increment will suffice in the case of a linear solution. For the nonlinear solution, a number of short time increments (as determined by experience) will be needed to reach static equilibrium.

Printout from the Incremental Solution program consists of some intermediate data generated during the course of the solution which has been useful during development of the program. It is in terms of modal responses and has limited physical significance. Further details may be found in Part 3 Programming Manual.

POSTPROCESSOR

The Postprocessor program allows the user to scan the large amount of output from the Incremental Solution and print selected data in a convenient format. It will normally be run more than once in a given analysis, because after a first look at a small amount of data the user will probably want more detailed information at critical locations in the structure.

The input file is Fortran logical unit 2 and is copied from the output tape generated by the Incremental Solution. There is no output file. Printout is controlled by card input data as described

under "Postprocessor Data". The first card allows the user to specify whether or not he wants to exercise selectivity with regard to time increments, joints, bars, membranes, and/or cells. It also provides for the input of a displacement scale factor. Cards 2 through 6 are used to indicate the type of data to be printed, such as displacements, forces, stresses, etc. Cards 7 through 10 provide title information which will be printed at the top of each page of printout. Finally, cards 20, 30, 40, 50, 60 contain user selected time increment numbers, joint numbers, bar numbers, membrane numbers, and cell numbers, respectively, consistent with the selectivity options indicated in card 1.

The deck setup for execution of the Postprocessor program consists of the appropriate JCL cards together with the card input data discussed above. The following pages show samples of the printout formats from the Postprocessor. Note that the results printed are at the end of a long (10 sec) time increment, and that the velocities and accelerations have damped out so that zero values are printed out. The results are applicable to the finite element model shown in Figure 14.

```
                         CARD INPUT DATA
  1        11000        =0.            =0        =0        =0        =0
  2        1111
  3        111
  4        1111
  5        1111
  6        1111
  7                  CARD 1, FIRST TITLE LINE
  8                  CARD 2, FIRST TITLE LINE
  9                  CARD 1, SECOND TITLE LINE
 10                  CARD 2, SECOND TITLE LINE
 20      9999    1=  10   =0   =0   =0   =0   =0   =0   =0   =0   =0   =0
 30      9999    1=  16   =0   =0   =0   =0   =0   =0   =0   =0   =0   =0
```

Notes: 1. Reference page 31 for explanation of input cards.

2. Card 20 indicates printout is desired for increments 1 through 10. Only the first increment is included here for demonstration of print formats.

3. The following pages are printed in the sequence shown for each time increment requested.

Sample printout of card input data

CARD 1, FIRST TITLE LINE CARD 2, FIRST TITLE LINE
CARD 1, SECOND TITLE LINE CARD 2, SECOND TITLE LINE
INCREMENT 1 AT TIME 10.000000 JOINT RESPONSE, DISPLACEMENTS SCALED BY .100000E+01

JOINT NO.	DISPLACEMENT X	DISPLACEMENT Y	DISPLACEMENT Z	COORDINATES X	COORDINATES Y	COORDINATES Z
1	0.	0.	0.	0.	0.	.100000E+01
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	.400000E+01	.100000E+01
4	0.	0.	0.	0.	.400000E+01	0.
5	.314083E-02	.373848E-03	-.162330E-01	.400314E+01	.373848E-03	.983767E+00
6	-.314062E-02	-.373889E-03	-.162329E-01	.399686E+01	-.373889E-03	-.162329E-01
7	.314036E-02	-.373781E-03	-.162330E-01	.400314E+01	.399963E+01	.983767E+00
8	-.314071E-02	.373832E-03	-.162329E-01	.399686E+01	.400037E+01	-.162329E-01
9	.428572E-02	-.364441E-05	-.506176E-01	.800429E+01	-.364441E-05	.949382E+00
10	-.427658E-02	.305247E-07	-.506130E-01	.799572E+01	.305247E-07	-.506130E-01
11	.428573E-02	.364061E-05	-.506176E-01	.800429E+01	.400000E+01	.949382E+00
12	-.427674E-02	-.408580E-07	-.506130E-01	.799572E+01	.400000E+01	-.506130E-01
13	.428452E-02	.570883E-08	-.141514E-03	.120043E+02	.570883E-08	.999858E+00
14	-.427681E-02	-.519514E-06	0.	.119957E+02	-.519514E-06	0.
15	.428451E-02	-.593021E-08	-.141514E-03	.120043E+02	.400000E+01	.999858E+00
16	-.427655E-02	.532609E-06	0.	.119957E+02	.400000E+01	0.

Sample printout of joint displacements and coordinates

```
CARD 1, FIRST TITLE LINE                                        CARD 2, FIRST TITLE LINE
CARD 1, SECOND TITLE LINE                                       CARD 2, SECOND TITLE LINE
 INCREMENT    1 AT TIME    10.000000  JOINT RESPONSE, DISPLACEMENTS SCALED BY     .100000E+01
```

JOINT NO.	VELOCITY X	VELOCITY Y	VELOCITY Z	ACCELERATION X	ACCELERATION Y	ACCELERATION Z
1	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.

Sample printout of joint velocities and accelerations

```
CARD 1, FIRST TITLE LINE                                                   CARD 2, FIRST TITLE LINE
CARD 1, SECOND TITLE LINE                                                  CARD 2, SECOND TITLE LINE
 INCREMENT    1 AT TIME    10.000000  MODAL RESPONSE
```

MODE	DISPLACEMENT	VELOCITY	ACCELERATION
1	.505740E-01	0.	0.
2	-.880341E-13	0.	0.
3	-.533321E-13	0.	0.
4	-.172371E-03	0.	0.
5	.413433E-13	0.	0.
6	-.165065E-03	0.	0.
7	-.134275E-12	0.	0.
8	-.139830E-04	0.	0.
9	-.415783E-12	0.	0.
10	-.742154E-13	0.	0.
11	-.641628E-05	0.	0.
12	-.199609E-13	0.	0.
13	.172409E-05	0.	0.
14	-.268180E-13	0.	0.
15	.248099E-06	0.	0.
16	.139942E-03	0.	0.
17	.196440E-13	0.	0.
18	.477193E-11	0.	0.
19	-.175946E-06	0.	0.
20	-.400006E-10	0.	0.
21	.399385E-07	0.	0.
22	.746542E-06	0.	0.
23	-.298251E-06	0.	0.
24	-.150719E-06	0.	0.
25	.238320E-06	0.	0.

Note: The modal response is generated by the Incremental Solution program and consists of three sets of amplitudes which are used to scale and combine the transformation modes (in this case 10 modes) to calculate the joint displacements, velocities and accelerations in the global X, Y, Z degrees of freedom.

Sample printout of modal response

```
CARD 1, FIRST TITLE LINE                                    CARD 2, FIRST TITLE LINE
CARD 1, SECOND TITLE LINE                                   CARD 2, SECOND TITLE LINE
 INCREMENT    1 AT TIME    10.000000  BAR ELEMENT RESPONSE

 BAR NO.             1              2
 FORCES     1   -.150004E+04   -.150004E+04
            2   -.150006E+04   -.150006E+04
 STRESSES 1     -.150005E+04   -.150005E+04
 STRAINS  1     -.141514E-03   -.141514E-03
 EQSTRESS 1      .150005E+04    .150005E+04
```

Lumped element forces $\overline{F}_1$ and $\overline{F}_2$, see Figure 1 (FORCES)

Average axial stress (STRESSES)

Corresponding strain (STRAINS)

Prandtl-Reuss equivalent stress, $\overline{\sigma}$, see note on page 106 (EQSTRESS)

Sample printout of bar element forces, stresses and strains

```
CARD 1, FIRST TITLE LINE                                             CARD 2, FIRST TITLE LINE
CARD 1, SECOND TITLE LINE                                            CARD 2, SECOND TITLE LINE
 INCREMENT    1 AT TIME    10.000000  MEMBRANE ELEMENT RESPONSE
```

MEM NO.		1	2	
FORCES	1	.458795E-01	-.127249E+00	Lumped element forces $\overline{F}_1$ through $\overline{F}_9$, see Figure 1
	2	.190860E+02	-.118275E+00	
	3	.195101E+02	.163129E-01	
	4	-.629297E-01	.298758E+01	
	5	-.140978E-01	.286167E+01	
	6	-.554987E-01	.910498E+00	
	7	-.108737E+00	.102787E+01	
	8	.113929E-01	-.730249E-01	
	9	.622506E-01	-.200622E+00	
STRESSES	1	.962976E+01	.143682E+01	Average stresses 1) σ_x, 2) σ_y, 3) τ_{xy}, see Figure 1
	2	-.226481E-01	.416181E+00	
	3	.229397E-01	-.636245E-01	
STRAINS	1	.909173E-06	.122593E-06	Corresponding strains
	2	-.301931E-06	-.546882E-08	
	3	.575657E-08	-.159661E-07	
EQSTRESS	1	.964119E+01	.125523E+01	Prandtl-Reuss equivalent stress, $\overline{\sigma}$

Note: The Prandtl-Reuss equivalent stress is equal to twice the octahedral shearing stress and is considered to be the failure criterion for an element, see Part 1, Appendix E for derivations and discussions. Therefore, if $\overline{\sigma} \geq \overline{\sigma}_r$ the element has failed, where $\overline{\sigma}_r$ is the rupture stress, see Table 5.

Sample printout of membrane element forces, stresses and strains

```
CARD 1, FIRST TITLE LINE                                      CARD 2, FIRST TITLE LINE
CARD 1, SECOND TITLE LINE                                     CARD 2, SECOND TITLE LINE
 INCREMENT    1 AT TIME   10.000000  CELL ELEMENT RESPONSE
```

CELL NO. FORCES	1	2
1	.174557E+00	.248279E+00
2	.230682E+04	.150435E+01
3	.230666E+04	.271226E+00
4	-.167831E+01	-.206266E+02
5	-.100713E+01	-.207296E+02
6	.692742E+04	.346874E+04
7	.346228E+04	.387766E+01
8	.692816E+04	.346666E+04
9	.346406E+04	.294727E+01
10	.150173E+00	.246621E+00
11	-.230702E+04	.213276E+01
12	-.230719E+04	.219289E+01
13	.544909E+00	.924056E+01
14	.851035E+00	.934880E+01
15	-.692888E+04	-.346084E+04
16	-.346406E+04	.352483E+01
17	-.692819E+04	-.346104E+04
18	-.346377E+04	.317168E+01
19	-.316205E-01	.233489E+00
20	-.346493E+04	-.346457E+04
21	-.233489E+00	.299106E+00
22	.346424E+04	.346395E+04
23	.249651E+03	.180340E+01
24	-.250392E+03	.196326E+01
25	.248994E+03	.673509E+01
26	-.251174E+03	.349102E+01
27	-.599555E+01	-.447089E+03
28	-.286040E+01	.529746E+02
29	-.331001E+01	-.449635E+03
30	-.340415E+01	.502800E+02

Lumped element forces $\bar{F}_1$ through $\bar{F}_{30}$, see Figure 2

Sample printout of cell element forces

```
CARD 1, FIRST TITLE LINE                                              CARD 2, FIRST TITLE LINE
CARD 1, SECOND TITLE LINE                                             CARD 2, SECOND TITLE LINE
 INCREMENT    1 AT TIME    10.000000  CELL ELEMENT RESPONSE
```

STRESSES	1	.199672E+04	-.156139E+02	Average stresses σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, τ_{zx} at point 1, see Figure 1
	2	.899911E+04	.300360E+04	
	3	.305837E+02	-.555116E+02	
	4	.917414E-01	.124443E+00	
	5	.250035E+03	.250011E+03	
	6	.728429E-02	-.236775E-02	
	7	-.199722E+04	.114475E+02	Average stresses σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, τ_{zx} at point 2, see Figure 1
	8	-.899985E+04	-.299684E+04	
	9	-.317395E+02	.679430E+01	
	10	.706239E-01	.123007E+00	
	11	.250035E+03	.250011E+03	
	12	.728429E-02	-.236775E-02	
STRAINS	1	-.927434E-04	-.932530E-04	Corresponding strains at point 1
	2	.785858E-03	.285572E-03	
	3	-.339438E-03	-.982590E-04	
	4	.230219E-07	.312282E-07	
	5	.627446E-04	.627387E-04	
	6	.182794E-08	-.594171E-09	
	7	.927549E-04	.941662E-04	Corresponding strains at point 2
	8	-.785877E-03	-.283288E-03	
	9	.339367E-03	.935823E-04	
	10	.177226E-07	.308677E-07	
	11	.627446E-04	.627387E-04	
	12	.182794E-08	-.594171E-09	
EQSTRESS	1	.817645E+04	.307005E+04	Prandtl-Reuss equivalent stresses at points 1 and 2, $\bar{\sigma}_1$ and $\bar{\sigma}_2$. See note on page 106.
	2	.817625E+04	.303699E+04	

Sample printout of cell element stresses and strains

SECTION IV
PROGRAM DIAGNOSTICS AND ERROR MESSAGES

This section contains lists of program diagnostics and error messages for the IMPACT Programs. In general, the messages are designed to point to discrepancies in the input data and are self-explanatory. Most represent fatal errors, although the program will continue to check as much of the input data as possible before the termination of the run. Some of the messages are informational or call the user's attention to a possible discrepancy, but they do not terminate execution. In some cases a message may indicate insufficient space allocation. Then the user may have to refer to Part 3 Programming Manual and/or seek program maintenance help.

LAMINATE GENERATOR

The following is a list of diagnostic messages printed by the Laminate Generator program. They are fatal errors unless noted otherwise.

1. NO LAYERS (DATA CODE 7) ENCOUNTERED IN INPUT. JOB TERMINATED.

2. NO CELLS (DATA CODE 40) ENCOUNTERED IN INPUT. JOB TERMINATED.

3. NO JOINTS (DATA CODE 2) ENCOUNTERED IN INPUT. JOB TERMINATED.

4. JOINT NO. XXXX LISTED IN DATA CODE 8 IS ABOVE A USER DEFINED JOINT - USER DEFINED JOINT WILL REMAIN UNCHANGED. (non-fatal)

5. CARD ENCOUNTERED IN DATA CODE 8 DUPLICATES EXISTING LAMINATE DATA. (non-fatal)

6. JOINT NO. XXXX LISTED IN DATA CODE 8 IS NOT FOUND IN LIST OF QUAD CORNER JOINTS - BAD JOINT DATA MAY RESULT. (non-fatal)

7. NO REVISED THICKNESSES (DATA CODE 8) ENCOUNTERED IN INPUT. (non-fatal)

8. GAP IN SEQUENCE (non-fatal)

9. ATTEMPT TO UNITIZE ZERO VECTOR. (non-fatal)

LOADS GENERATOR

The following is a list of diagnostic messages printed by the Loads Generator Program. They are fatal unless noted otherwise.

1. A 29999 CARD WAS NOT FOUND.

2. NO JOINT COORDINATE DATA (DATA CODE 2) ENCOUNTERED IN INPUT.

3. NO CONSTANTS (DATA CODE 11) ENCOUNTERED IN INPUT.

4. INCREMENT (BETA) NUMBER XXXX NOT FOUND IN DATA CODE 11 DATA.

5. NO LOADED JOINT NUMBERS (DATA CODE 12) ENCOUNTERED IN INPUT.

6. JOINTS FOR INCREMENT (BETA) NUMBER XXXX NOT FOUND IN DATA CODE 12 DATA.

7. ATTEMPT TO UNITIZE ZERO VECTOR (non-fatal)

INITIAL GENERATOR

The following is a list of diagnostic messages printed by the Initial Generator Program. They are grouped under subroutine names which are not described here. Subroutine descriptions may be found in Part 3, Programming Manual.

BIRDG1

1. DATA CODE 1 INPUT IN ERROR.

2. (BIRDG1) TBASE = 0 DATA INPUT ERROR. JOB ABORTED. DATA SCAN CONTINUES.

ACCPRP

1. (ACCPRP) MATERIAL REFERENCE NUMBER OUT OF RANGE.
   REQUESTED MATERIAL NUMBER NO. NNNNN
   MAXIMUM MATERIALS NNNNN

2. FATAL ERROR CONDITION EXISTS OUTSIDE OF THE MATERIAL PROPERTIES ACCESS MODULE, NO ACCESS ATTEMPTED.

CNSTRN

1. ALL DIRECTION COMPONENTS ARE ZERO.
   DATA CODE = NN
   CONSTRAINT NO. = NNNNN
   JOINT M = NNNNN
   JOINT N = NNNNN
   DIRECTION NO. = NNNNN
   DIRECTIONS
   NNNNNNN,NNN

2. INVALID DATA IN THE DIRECTION TABLE ASSOCIATED WITH DIREC NO. N

3. INVALID DIRECTION NUMBER. MAX DIREC. NO.=NNNNN

4. INVALID JOINT NUMBER.

5. CONSTANT TABLE DATA OUT OF SEQUENCE, CONSTRAINT NUMBER EXPECTED NNNNN

6. INVALID DATA CODE.

7. THE NUMBER OF CONSTRAINTS EXCEEDS THE PROGRAM MAXIMUM OF NNNNN

8. CONSTRAINT DATA INPUT MISSING.

9. THE NUMBER OF OBLIQUE CONSTRAINTS EXCEEDS THE MAXIMUM OF NNNNN

COCALC

1. ERROR DETECTED IN SUBROUTINE COCALC
   MATRIX ASC IS EITHER SINGULAR OR NEAR SO.

DRCNUM

1. ALL DIRECTION NUMBERS ARE ZERO. A UNIT VECTOR PARALLEL TO THE X AXIS IS ENTERED.

2. JOINT NUMBER OUT OF RANGE.
   MAXIMUM JOINT = NNNNN
   JOINT M = NNNNN
   JOINT N = NNNNN
   DIRECTION NUMBER NNNNN
   FIXUP TAKEN, BAD DATA FLAGGED IN DIREC TBL.

3. DIRECTION COSINE RECORDS NOT IN SEQUENCE.
   NNNNN RECORDS READ
   ERRONEOUS RECORD
   ID NDIREC JNTM JNTN IBLNK DIREC

4. INVALID DATA CODE IN DIRECTION NUMBER INPUT
   ERRONEOUS RECORD
   ID NDIREC JNTM JNTN IBLNK DIREC

5. THE NUMBER OF DIRECTION NUMBERS EXCEEDS THE PROGRAM MAXIMUM OF 50.

EDGDOF

1. *** SUBROUTINE EDGDOF, FATAL ERROR PRIOR TO ENTRY
   EDGDOF WILL NOT BE EXECUTED.

2. *** ERROR DETECTED IN SUBROUTINE EDGDOF
   NNNNN JOINT PAIRS WRITTEN TO TAPE IN SUBR EDGES
   NNNNN JOINT PAIRS READ FROM TAPE IN EDGDOF

EDGES

1. *** ERROR IN SUBROUTINE EDGES
   INVALID DATA CODE NNNNNNNN

ELEMNT

1. (ELEMNT) ELEMENT NO. OUT OF SEQUENCE.
   PREVIOUS SEQUENCE NO. = NNN
   CURRENT CARD SEQUENCE NO. = NNN

2. (ELEMNT) ELEMENT TYPE CODE OUT OF SEQUENCE OR 9999 SEPARATOR CARD MISSING,
   PREVIOUS TYPE CODE = NNN
   CURRENT CARD TYPE = NNN
   ELEMENT NUMBER = NNNNN

3. (ELEMNT) A = 0 FOR BAR ELEMENT NNNNN

4. (ELEMNT) T = 0 FOR MEMBRANE ELEMENT NNNNN

5. (ELEMNT) MR = 0 FOR ELEMENT NNNNN CODE = NNN

6. (ELEMNT) JOINT NUMBER(S) FOR ELEMENT NNNNN IS (ARE) GREATER THAN MAX
   JOINT INPUT = NNNNN
   JOINT NUMBERS INPUT ARE P0, Q0, R0, S0, P1, Q1, R1, S1

7. (ELEMNT) JOINT NUMBER(S) FOR ELEMENT NNNNN IS (ARE) EQUAL ZERO,
   JOINT NUMBERS INPUT ARE P0, Q0, R0, S0, P1, Q1, R1, S1

JTEMP

1. (JTEMP) DATA CODE ERROR READING TEMPERATURE DATA.
   ICODE = NN J1,J2 = NN NN TEMP = .NNNNNN ENN

2. (JTEMP) JOINT NO. NOT INPUT FOR TEMPERATURE DATA.
   ICODE = NN   J1,J2 = NN   NN   TEMP =.NNNNNN ENN

JZERO

1. (JZERO) DATA CODE ERROR READING COORDINATE DATA.
   ICODE = NN   J = NN   X,Y,Z = .NNNNN ENN .NNNNN ENN .NNNNN ENN

2. (JZERO) JOINT NO. NOT INPUT FOR COORDINATE DATA.
   ICODE = NN   J = NN   X,Y,Z = .NNNNN ENN .NNNNN ENN .NNNNN ENN

3. (JZERO) JOINT NO. OUT OF SEQUENCE.
   ICODE = NN   J = NN   X,Y,Z = .NNNNN ENN .NNNNN ENN .NNNNN ENN

LPCKC

1. LPCKC-SID *** KBAR = D INVERSE ERROR.
   CELL DEFINED BY JOINTS NNNN NNNN NNNN NNNN NNNN NNNN NNNN
   NNNN HAS GENERATED A SINGULAR MATRIX AND CANNOT BE INVERTED.

2. LPCKC-SID *** KBAR = D MATRIX HAS ONLY ABOUT NNNN.N SIGNIFICANT
   DIGITS.
   CELL DEFINED BY JOINTS NNNN NNNN NNNN NNNN NNNN NNNN NNNN
   NNNN

LPMKC

1. LPMKC-SID *** KBAR = D INVERSE ERROR.
   MEMBRANE DEFINED BY JOINTS NNNN NNNN NNNN NNNN
   HAS GENERATED A SINGULAR MATRIX AND CANNOT BE INVERTED.

2. LPMKC-SID *** KBAR = D MATRIX HAS ONLY ABOUT NNNN.N SIGNIFICANT
   DIGITS.
   MEMBRANE DEFINED BY JOINTS NNNN NNNN NNNN NNNN

MATDES

1. MATERIAL REFERENCE NUMBER NN BEING PROCESSED
   AND MATERIAL REFERENCE NO. NN WAS ENCOUNTERED.
   THE ERRONEOUS RECORD
   IDCODE NTRY NPC MAP REC CONT
   *** ERROR DETECTED IN SUBROUTINE MATDES

2. INVALID IDCODE NN ENCOUNTERED WHILE PROCESSING MATERIAL
   PROPERTIES DATA
   THE ERRONEOUS RECORD .
   IDCODE NTRY NPC MAP REC CONT
   *** ERROR DETECTED IN SUBROUTINE MATDES

3. INSUFFICIENT SPACE ALLOCATED FOR MATERIAL DESCRIPTION
   STATEMENTS, MODIFY VARIABLE MXDES IN SUBR. MTLMOD.
   THE ERRONEOUS RECORD .
   IDCODE NTRY NPC MAP REC CONT
   *** ERROR DETECTED IN SUBROUTINE MATDES

MTLMOD

1. *** ERROR DETECTED IN SUBROUTINE MTLMOD
   NO MATERIAL DESCRIPTION INPUT FOR REFERENCE NUMBER NNNNN

2. *** ERROR DETECTED IN SUBROUTINE MTLMOD
   MATERIAL REFERENCE NO. OUT OF RANGE
   SPACE ALLOCATED FOR NNNNN ERRONEOUS MTRL. REF. NO. NNNNN
   IF MODIFICATION OF THE PROGRAM IS NECESSARY THEN
   MODIFY VARIABLE MXMTRL IN SUBR. MTLMOD,
   MODIFY SUBSCRIPTS IN VARIABLES LNGTHS,
   AND MPTR IN LABELED COMMON MTRL.

3. *** ERROR DETECTED IN SUBROUTINE MTLMOD
   INVALID DATA CODE NN ENCOUNTERED
   IDCODE NTRY NPC MAP REC CONT

4. *** ERROR DETECTED IN SUBROUTINE MTLMOD
MATERIAL REFERENCE NO. OUT OF SEQUENCE OR MISSING
MATERIALF REFERENCE NO. LAST ENCOUNTERED NNNNN
MATERIAL REFERENCE NO. JUST ENCOUNTERED NNNNN

5. *** ERROR DETECTED IN SUBROUTINE MTLMOD

OVER3

1. (OVER3) ERROR IN CONSTRAINT TABLE GENERATION
MORE THAN 3 ENTRIES FOR JOINT NNNNN

CONSTRAINT NO.	JOINT NO.	DIRECTION VALUE
NNNNN	NNNNN'	NNNNN

PASSM2

1. ERROR (PASSM2) DUPLICATE CONSTRAINTS AT JOINT NNNNN

PROP

1. PROCESSING MATERIAL REF. NO. NNNNN PROPERTY NO. NNNNN
SPACE ALLOCATED FOR NNNNN PROPERTIES MAXIMUM.
MODIFY VARIABLE MXPROP IN SUBR. MTLMOD,
MODIFY SUBSCRIPTS IN VARIABLES LNGTHS, MPTR, AND
PRPVAL IN LABELED COMMON MTRL.
MOD. SUBSCRIP IN VAR. COEF AND VAR MXPROP IN SUBROUTINE ACCPRP
*** ERROR DETECTED IN SUBROUTINE PROP

2. PROCESSING MATERIAL REF. NO. NNNNN PROPERTY NO. NNNNN
THE NUMBER OF COEF.S READ NNNNN DOES NOT EQUAL THE NUMBER
SPECIFIED TO BE INPUT NNNNN

3. PROCESSING MATERIAL REF. NO. NNNNN PROPERTY NO. NNNNN
THE NUMBER OF COEF.S SPECIFIED TO BE CALCULATED NNNNN IS
GREATER THAN THE NUMBER OF VALUES INPUT NNNNN

4. PROCESSING MATERIAL REF. NO. NNNNN PROPERTY NO. NNNNN
THE NUMBER OF COEF.S NNNNN WILL OVERFLOW THE SPACE NNNNN
ALLOCATED FOR ALL COEFFICIENTS.
MODIFIED VARIABLE MXCOFS IN SUB. MTLMOD,
MODIFY SUBSCRIPTS IN VARIABLE COEFS IN LABELED COMMON MTRL.

5. PROCESSING MATERIAL REF. NO. NNNNN PROPERTY NO. NNNNN
MORE PROPERTY VALUES TO BE INPUT THAN SPACE AVAILABLE NNNNN
MODIFY VARIABLE MXPVL IN SUB. MTLMOD,
MODIFY SUBSCRIPTS IN ARRAYS TVPA, TVPAT, AND VPT.

6. PROCESSING MATERIAL REF.NO. NNNNN PROPERTY NO. NNNNN
MORE COEFFICIENTS TO BE INPUT NNNNN THAN SPACE AVAILABLE NNNNN
MODIFY VARIABLE MXPCO IN SUB. MTLMOD,
MODIFY SUBSCRIPTS IN ARRAYS TVPA, TVPAT, AP, RTMP,
ITMP, ASC, AND BSC IN LABELED COMMON COFCLC.

7. PROCESSING MATERIAL REF.NO. NNNNN PROPERTY NO. NNNNN
MATERIAL REFERENCE NUMBER WAS EXPECTED.

8. DATA CODE NNNNN WAS ENCOUNTERED INSTEAD OF 10.
ERRONEOUS RECORD
IDCODE NTRY NPC MAP REC1 REC2 REC3 REC4 REC5 REC6

RAMOSG

1. (RAMOSG) R = 1.0

MTLERR	EA/E	SR	R	N K =1
.NNNN ENN	.NNNN ENN	.NNNN ENN	.NNNN ENN	.NNNN ENN

MR	E	EA	SIGA	SIGR
NN	.NNNN ENN	.NNNN ENN	.NNNN ENN	.NNNN ENN

2. (RAMOSG) ZERO ARGUMENT CALCULATED FOR NATURAL LOG FUNCTION.
MTLERR = NNN

MR	E	EA	SIGA	SIGR
NN	.NNNN ENN	.NNNN ENN	.NNNN ENN	.NNNN ENN

3. (RAMOSG) RAMBERT-OSGOOD VALUES DID NOT CONVERGE WITHIN 50
ITERATIONS, MTLERR = NN.

MR	E	EA	SIGA	SIGR
NN	.NNNN ENN	.NNNN ENN	.NNNN ENN	.NNNN ENN

SKDATA

1. (SKDATA) INPUT DATA OUT OF SEQUENCE, ATTEMPT TO SKIP CODE NN
   FAILED WHEN THE FOLLOWING CARD WAS ENCOUNTERED.
   ID9999A A A A A A
   NNYYYAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA

FORMAT PHASE 2

Diagnostic messages printed by the FORMAT program are not listed here but are available in Reference 1.

INCREMENTAL SOLUTION

The following is a list of diagnostic messages printed by the Incremental Solution program:

1. TIME NOT SPECIFIED IN ASCENDING ORDER. STOP.

2. INSUFFICIENT WORK SPACE BY XXXXX WORDS. STOP.

3. UNCORRECTABLE SINGULAR EIGENVECTORS. HALT.

POSTPROCESSOR

When an error is detected by the Postprocessor program, the following message is printed at the top of the last page of output.

***** ERROR nnnn DETECTED *****

The error number nnnn is an integer having the values and meanings described below.

nnnn	Description
1-6	Input card nnnn is out of sequence
7	One of the input title cards (7 through 10) is out of sequence
21	Increment selectivity option was specified but selection table (card 20) is not present
22	Null increment selection table
30	Inconsistent options for joint data between selectivity flag and joint subset selection flags
31	Joint selectivity option was specified but selection table (card 30) is not present
32	Null joint selection table
40	Inconsistent options for bar data between bar selectivity flag, bar subset selection flags and/or presence of bar elements in model
41	Bar selectivity option was specified but selection table (card 40) is not present
42	Null bar selection table
50,51,52	Same as 40, 41, 42 except substitute "membrane" for "bar"
60,61,62	Same as 40, 41, 42 except substitute "cell" for "bar"
100	Insufficient core available

When the error number nnnn is equal to 100, the following additional message is printed out.

*** INSUFFICIENT CORE XXXX   VS   YYYY

The first integer value XXXX is equal to the core available and the second value YYY is the core required.

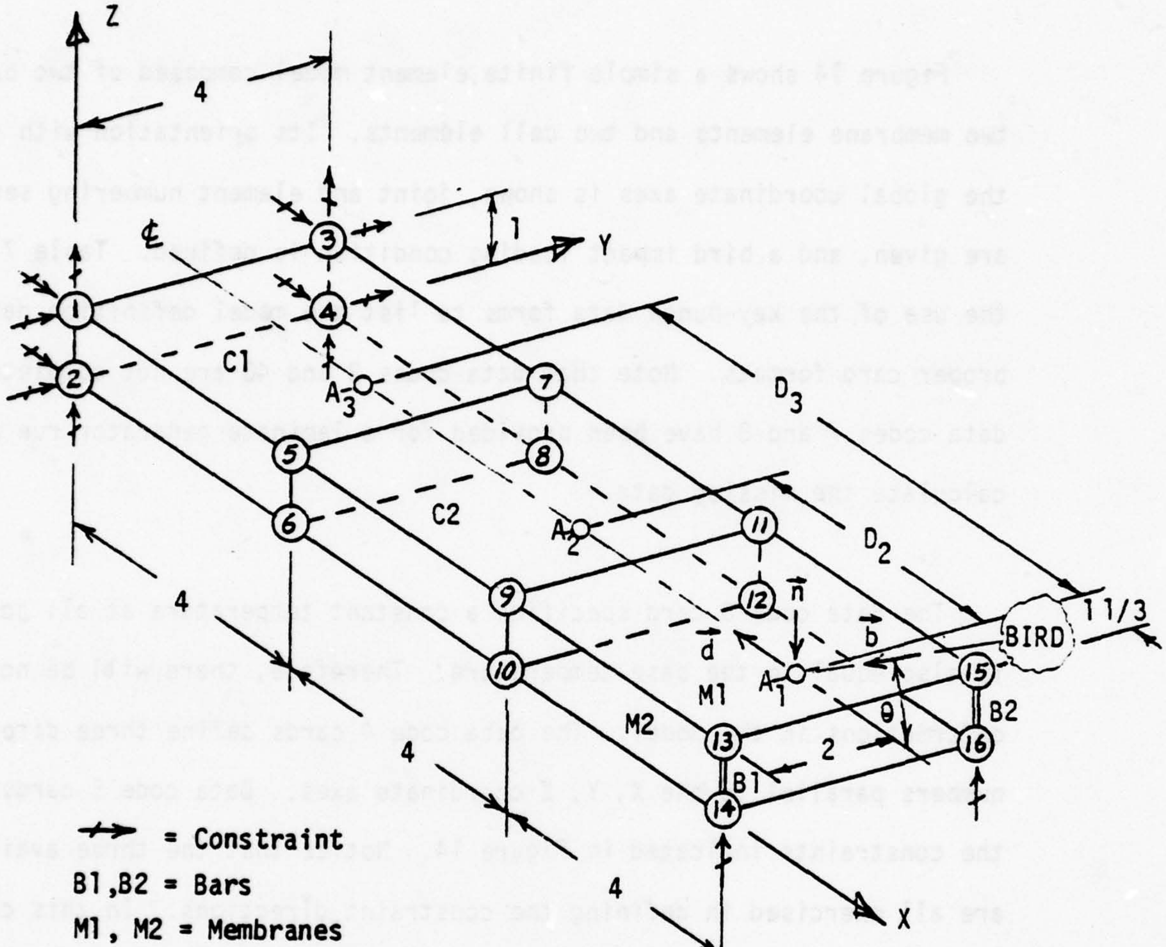
SECTION V

ILLUSTRATIVE EXAMPLES

Figure 14 shows a simple finite element model composed of two bar elements, two membrane elements and two cell elements. Its orientation with respect to the global coordinate axes is shown, joint and element numbering sequences are given, and a bird impact loading condition is defined. Table 7 illustrates the use of the key-punch data forms to list the model definition data in the proper card formats. Note that data codes 2 and 40 are not complete and that data codes 7 and 8 have been provided for a laminate generator run which will calculate the missing data.

The data code 3 card specifies a constant temperature at all joints, which is also equal to the base temperature. Therefore, there will be no thermal deformations in the model. The data code 4 cards define three direction numbers parallel to the X, Y, Z coordinate axes. Data code 5 cards impose the constraints indicated in Figure 14. Notice that the three available options are all exercised in defining the constraint directions. In this case the most convenient option is probably the reference to data code 4 direction numbers.

The model in Figure 14 has only one layer of cell elements, but the Laminate Generator can still be used to calculate lower surface joint coordinates and to complete the single layer cell definitions. In the data code 7 cards a laminate number of 100 is specified, and the surface offset field is blank ($t_0 = 0$). Therefore, the program will use the surface joint coorinates as given without offset normal to the surface. Only one layer



= Constraint

B1, B2 = Bars

M1, M2 = Membranes

C1, C2 = Cells

$\sin \theta = .6$

Bird mass = .004, Velocity = 5000, L = 15

Length of time increments = .001 sec

A_1, A_2, A_3 = Travelling footprint c.g.'s

Figure 14. A Simple Finite Element Model for Purposes of Illustration.

definition card ($L + \ell = 101$) is needed in this case, but if the laminate had more than one layer there would be additional layer definition cards 102, 103, etc. The data code 8 cards are not really necessary since no change in layer thicknesses is being made, but they illustrate the procedure. If the laminate had more layers, fields t_2, t_3, etc. would also contain overriding thickness values.

The data code 10 cards illustrate the input of room temperature properties for aluminum (based on equations 15 through 18) and for polycarbonate (based on preliminary data for Reference 3). Temperature dependence for any property would be input by specifying the desired number of polynomial coefficients in field NC and giving temperature, property value pairs in fields T_i, V_i.

Data codes 11 and 12 are provided so that a Loads Generator run can be executed to calculate the bird impact loads. In this case a travelling footprint loading has been specified with a rectangular force-time distribution, see data code 11, cards 6. The user should recognize that he may also specify a stationary footprint loading by setting $D = 0$ for all β. Likewise, the force-time distribution may be controlled by means of the load distribution factors f.

Element definitions on data code 20, 30, 40 and 50 cards show complete bar and membrane definitions but only partial cell data. The Laminate Generator will produce the data for fields p_1, q_1, r_1, s_1 and M. If the stress orientation angle ζ_{pq} is non-zero for any surface cell, it should be entered by the user, since the Laminate Generator does not calculate this angle. However, it does duplicate the surface cell angle input by the user for all other cells in a

stack in the case of a multi-layered laminate.

Table 8 illustrates FORMAT deck setup 1 card data entered on a key-punch form. Deck setups 2 and 3 are generated in a similar manner.

Table 9 shows the data cards for the Incremental Solution and Postprocessor programs. The impact loading will be acting on and travelling along the surface of the structure for the first three increments only, but inertia forces could cause more critical response after impact than during impact. Therefore, ten time increments are specified for the incremental solution. The Postprocessor cards specify that results will be printed for time increments 1 through 6. The results printed are to include the following:

1. Joint coordinates, displacements, velocities and accelerations for joints 1 through 12.
2. Modal displacements, velocities and accelerations.
3. Lumped element forces, average stresses, average strains and equivalent stresses for all bar, membrane and cell elements.

For larger models than that shown in Figure 14, the user will normally make a first Postprocessor run to print a more limited selection of results. Then, after inspection of this select information, he will know better what information to print out in subsequent Postprocessor runs for detailed evaluation of results.

TABLE 7. MODEL DEFINITION DATA LISTED ON KEY-PUNCH FORMS

DAC 25-1212C (REV 8 69)

RIGHT ADJUSTED INTEGER DATA					FLOATING POINT DATA				TYPE OF DATA
1					BASE TEMPERATURE T_B	MECH EQUIV OF HEAT J			CONSTANTS
2	JOINT				X - COORDINATE	Y - COORDINATE	Z - COORDINATE	JT TEMP T_J	JOINT COORD'S
3	JOINT a	JOINT b						JT TEMP T_J	JOINT TEMP'S
4	DIR NO	JOINT m	JOINT n		X DIR COSINE ℓ_x	Y DIR COSINE ℓ_y	Z DIR COSINE ℓ_z		DIRECTION NO'S
5	CONSTR	JOINT m	JOINT n	DIR NO	ℓ_x	ℓ_y	ℓ_z		CONSTRAINTS
1 2	3 4 5 6	7 8 9 10	11 12 13 14	15 16 17 18	19 … 33	34 … 48	49 … 63	64 … 72	73 … 80
1					75.0	9332.			
1					1.0 E+6	1.0 E-12			
1	9999								
2	1						1.0		
2	3					4.0	1.0		
2	5				4.0		1.0		
2	7				4.0	4.0	1.0		
2	9				8.0		1.0		
2	11				8.0	4.0	1.0		
2	13				12.0		1.0		
2	14				12.0				
2	15				12.0	4.0	1.0		
2	16				12.0	4.0			
2	9999								
3	1	16						75.0	
3	9999								
4	1				1.0				
4	2					1.0			
4	3						1.0		
4	9999								

TABLE 7. (Continued)

DAC 35 1212C (REV 8-69)

RIGHT ADJUSTED INTEGER DATA					FLOATING POINT DATA				
1					BASE TEMPERATURE T_B	MECH EQUIV OF HEAT J			TYPE OF DATA CONSTANTS
2	JOINT				X - COORDINATE	Y - COORDINATE	Z - COORDINATE	JT TEMP T_J	JOINT COORD'S
3	JOINT a	JOINT b						JT TEMP T_J	JOINT TEMP'S
4	DIR NO	JOINT m	JOINT n		X DIR COSINE ℓ_x	Y DIR COSINE ℓ_y	Z DIR COSINE ℓ_z		DIRECTION NO'S
5	CONSTR	JOINT m	JOINT n	DIR NO	ℓ_x	ℓ_y	ℓ_z		CONSTRAINTS
1 2	3 4 5 6	7 8 9 10	11 12 13 14	15 16 17 18	19–33	34–48	49–63	64–72	73–80
5	1	1		1					
5	2	1		2					
5	3	1		3					
5	4	2	6						
5	5	2	4						
5	6	2	1						
5	7	3			1.0				
5	8	3				1.0			
5	9	3					1.0		
5	10	4		1					
5	11	4		2					
5	12	4		3					
5	13	14		3					
5	14	16		3					
5	9999								

TABLE 7. (Continued)

DAC 25-1212C (REV 8-69)

DATA CODE 7, LAMINATE DEFINITION DATA

RIGHT ADJUSTED INTEGER DATA					FLOATING POINT DATA
7	L				t_0
7	L + ℓ	N_ℓ	ΔJ_ℓ	ΔE_ℓ	t_ℓ
7	L + 99				
1 2	3 4 5 6	7 8 9 10	11 12 13 14	15 16 17 18	19 – 33
7	100				
7	101	200	1	1	1.0
7	199				
7	9999				

TABLE 7. (Continued)

DAC 35-1313C (REV 8-69)

DATA CODE 8, LAMINATE VARIABLE THICKNESS DATA

Non- blank for continuation

RT ADJ INTEGER			FLOATING POINT DATA							
8	JTa	JTb	t_1	t_2	t_3	t_4	t_5	t_6	Non-blank for continuation	
1-2	3-6	7-10	11-20	21-30	31-40	41-50	51-60	61-70	71-72	73-80
8	1		1.0							
8	3		1.0							
8	5	11	1.0							
8	9999									

TABLE 7. (Continued)

RT ADJ INTEGER				ALPHAMERIC DATA — Card column 72 non-blank for continuation							
1 0	M			MATERIAL DESCRIPTION						☒	
RT ADJ INTEGER				FLOATING POINT DATA							TYPE OF DATA
1 0	M + P		NC	T_1	V_1	T_2	V_2	T_3	V_3	☒	TEMP-VAL PAIRS
1 0	M + P	NI		a_0	a_1	a_2	a_3	a_4	a_5	☒	POLYNOM COEF'S
1 0	M + 99	End of data for material M									
1 2	3 4 5 6	7 8	9 10	11–20	21–30	31–40	41–50	51–60	61–70	71 72	73–80
10	100			ALUMINUM, 2024-T62, RM TEMP							
	101	1		10.6 E+6							
	102	1		7.44 E+6							
	103	1		50000.							
	104	1		66800.							
	105	1		.0488							
	106	1		.33							
	107	1		.126 E-4							
	108	1		.259 E-3							
	109	1		80.							
	110	1		1.0 E-9							
	199										
	200			POLYCARBONATE (SEIRRACIN, LOW STRAIN RATE), RM TEMP							
	201	1		.27 E+6							
	202	1		.143 E+6							
	203	1		9076.							
	204	1		11936.							
	205	1		.531							
	206	1		.35							
10	207	1		.347 E-4							

TABLE 7. (Continued)

RT ADJ INTEGER | ALPHAMERIC DATA — Card column 72 non-blank for continuation

1 0 | M | MATERIAL DESCRIPTION

RT ADJ INTEGER | FLOATING POINT DATA | TYPE OF DATA

Cols 1–2	Cols 3–6	Cols 7–8	Cols 9–10	Cols 11–20	Cols 21–30	Cols 31–40	Cols 41–50	Cols 51–60	Cols 61–70	Col 72	Cols 73–80
1 0	M + P		NC	T_1	V_1	T_2	V_2	T_3	V_3	☒	TEMP-VAL PAIRS
1 0	M + P	NI		a_0	a_1	a_2	a_3	a_4	a_5	☒	POLYNOM COEF'S
1 0	M + 99	End of data for material M									
10	208	1		.1114 E-3							
10	209	1		108.							
10	210	1		.36 E-4							
10	299										
10	9999										

TABLE 7. (Continued)

RT	ADJUSTED INTEGER DATA				FLOATING POINT DATA			
1 1	1	$3a_1$			m	v	L	DATA CODE 11, BIRD IMPACT DEFINITION DATA
1 1	2	$n_{1\beta}$			b_x	b_y	b_z	
1 1	3				n_x	n_y	n_z	
1 1	4				d_x	d_y	d_z	
1 1	5				X_o	Y_o	Z_o	
1 1	6	β			D	f		
1 2	3 4 5 6	7 8 9 10	11 12 13 14	15 16 17 18	19–33	34–48	49–63	64–80
1,1	1	48			.004	5000.	15.0	
↑	2	3			-.8		-.6	
	3						-1.0	
	4				-1.0			
	5				11.0	2.0	1.0	
	6	1				1.0		
	6	2			4.0	1.0		
↓	6	3			8.0	1.0		
1,1	9999							

TABLE 7. (Continued)

DAC 25-1212C (REV 8-69)

DATA CODE 12, IMPACT FOOTPRINT DATA

RIGHT ADJUSTED INTEGER DATA

Card column 72 non-blank for continuation

1 2	β	$J_{1\beta}$	$J_{2\beta}$	$J_{3\beta}$	$J_{4\beta}$	$J_{5\beta}$	$J_{6\beta}$	.	.	.	.	.						
12	1	9	11	13	15													
12	2	5	7	9	11													
12	3	1	3	5	7													
12	9999																	

TABLE 7. (Continued)

DAC 35-1312C (REV 8-69)

ELEMENT DEFINITION DATA

RIGHT ADJUSTED INTEGER DATA											FLOATING POINT DATA			TYPE OF DATA
2 0	BAR NO	p	q							M	AREA A			BAR ELEMENT
3 0	MEM NO	p	q	r	s					M	THICKNESS t			MEMBRANE ELEM
4 0	CELL NO	p_o	q_o	r_o	s_o	p_1	q_1	r_1	s_1	M		ζ_{pq} ξ_{pq}		CELL ELEMENT
5 0	PT MASS	p									M_{px}	M_{py}	M_{pz}	POINT MASS ELEM
1-2	3-6	7-10	11-14	15-18	19-22	23-26	27-30	31-34	35-38	39-42	43-52	53-62	63-72	73-80
20	1	13	14							100	4.0			
20	2	15	16							100	4.0			
20	9999													
30	1	13	9	11	15					100	.5			
30	2	14	10	12	16					100	.5			
30	9999													
40	1	5	1	3	7									
40	2	9	5	7	11									
40	9999													
50	9999													

TABLE 8. FORMAT INSTRUCTIONS ON KEY-PUNCH FORMS

DAC 25 1212C (REV 8-69)

FORMAT Deck Setup 1, reference page 6[illegible]

```
$FØRMAT       STANDARD
$RUN          GØ, LØGIC
      INPUT TAPE (MTAPE, 1)
      INPUT TAPE (LTAPE, 1)
      ØUTPUT TAPE (DECØMP, 1)
$INSTRUCTIØN
      PT PPT = DPØT .PEJCØL. (1)
      SAVE (DECØMP) DPØT
      MR     = PRUF MEL .SEQWF.
      PRUPJ PRUPS = PRUPT .PEJCØL. (4B)
      PR     = PRUPJ .MULT. PT
      PRT    = PR .TRANSP.
      X LTL UR = PRUF KEL .SEQWF. PRT
      UT     = PRUPJ .TMULT. UR
      SAVE (DECØMP) MK PRUPJ LTL, UR
      PRINT (   ) UT
$END
```

TABLE 9. INCREMENTAL SOLUTION AND POSTPROCESSOR DATA CARDS

DAC 25 1212C (REV 8-69)

```
    1    6   10   25F    16 15000                        } Incremental
   .001      .002        .003        .004       .005       .006 } Solution cards
   .007      .008        .009        .010                       } ref pg 69

1         1.1000                                         }
2         1.111                                          }
3         1.11                                           }
4         1.111                                          }
5         1.111                                          } Post-
6         1.111                                          } processor
7            PØSTPRØCESSØR PRINTØUT FØR SIMPLE FINITE ELEMENT MØDEL SUBJE } cards,
8         CTED TØ BIRD IMPACT                            } ref pg 71
9            BIRD MASS = .004, VELØCITY = 5000           }
10                                                       }
209999          1-   6                                   }
309999          1-  12                                   }
```

APPENDIX A

SECTIONS II AND III OF
AFFDL-TR-77-99 PART 3

APPENDIX A

SECTIONS II AND III OF

AFFDL-TR-77-99 PART 3

This appendix contains direct duplications Sections II and III of the Part 3 Programming Manual. These sections are presented here for the purpose of providing the user with example deck setups, including JCL, for standard operations at the Wright-Patterson Air Force Base CDC Computing Facility. At other installations this information may not be completely applicable, but additional information concerning implementation and execution of the IMPACT Programs is available in Part 3.

SECTION II
SYSTEM OVERVIEW

The user initiates an analysis by preparing tabular data which describes the idealized model of the windshield system under investigation. The model may include support structure for the transparency which may itself consist of a number of laminates. The tabular data prepared by the user, consisting of geometry, constraint, material property, and element definition data, is described in detail in Part 2.

PROGRAM FUNCTIONS

The Laminate Generator provides a preprocessing function with respect to multi-layered transparencies. Optionally, the user may prepare the model definition data consistent with the requirements of the Laminate Generator. The program will then augment the input model definition data with the joint coordinates and element definitions of interior joints and elements within a laminate. In addition, surface normal vectors representing a unit pressure distribution over the exterior surface of the transparency are generated. When applicable, this program reduces the amount of input data prepared by the user and provides vector data for use in assembling pressure loading conditions in subsequent analysis steps.

The Initial Generator serves the prime function of transforming the complete model definition data in tabular form into matrix data consistent with the requirements of the subsequent solution process. Using the model definition data, the unassembled element stiffness, damping, and mass matrices are generated as are other matrices of geometric transformations, thermal effects, etc. The data generated here is independent of mechanical loading on the structure and satisfies the requirements of either a linear and non-linear analysis whichever might follow.

The Loads Generator provides the means of computing discrete joint

loads on the idealized model as a function of time and bird length, mass, velocity, and impact direction. Optionally, the user may prepare the model definition data to include the description of the impact loading consistent with the requirements of the Loads Generator. The program will then generate a matrix of incremental joint loads at the times specified in either card image or binary form.

The FORMAT Phase II program is used to assemble the structural mass and stiffness matrices, decompose the structural stiffness matrix, extract vibration modes, perform the modal transformation, and produce properly ordered binary output data files for input to the incremental solution step. Input to this processing step are the binary file of matrices from the Initial Generator and, optionally, the loads matrix from the Loads Generator in either card image form or as a binary matrix in a separate file. The required tasks in this phase of the solution process may be accomplished in one or more executions of the FORMAT program.

The Linear and Non-Linear Incremental Solution programs solve the equations of motion incrementally for the modal response, structural displacements, and element forces, stresses, and strains. The results from each increment are output to a binary file for subsequent processing. The format and content of the output file is identical for either a linear or non-linear solution.

The Postprocessor accepts the output file from either a linear or non-linear solution and selectively prints the results. Selection may be specified for time increments, joints, modes, and elements in any logical combination.

DATA FILES

Figure A.1 shows the flow of data through a complete solution. Each data file is identified for subsequent reference in this discussion,

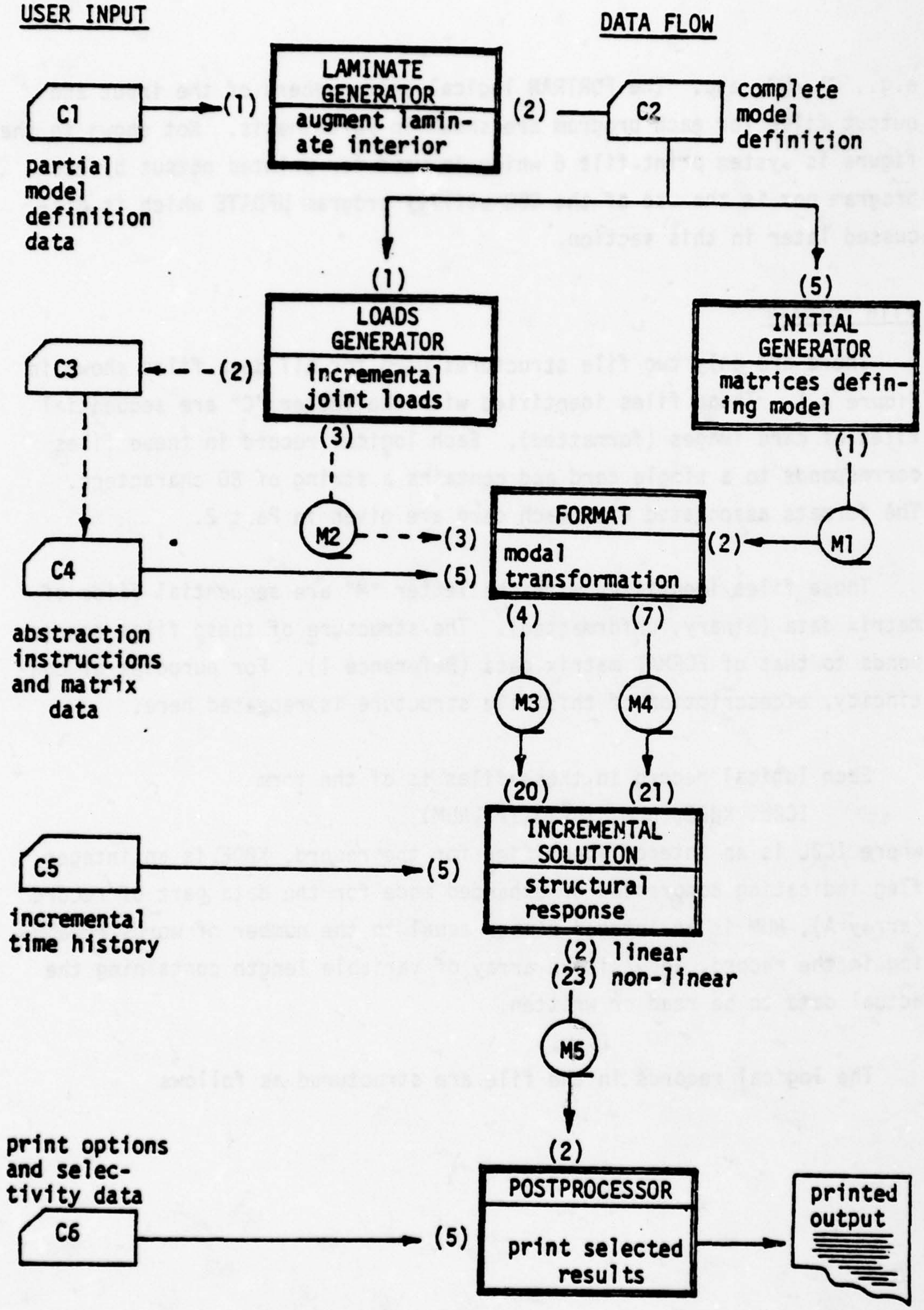


Figure A.1. Data Flow Through Complete Solution

e.g., C1, M3, etc. The FORTRAN logical unit numbers of the input and output files for each program are shown in parenthesis. Not shown in the figure is system print file 6 which is used for printed output by each program nor is the use of the CDC utility program UPDATE which is discussed later in this section.

File Formats

There are only two file structures used for all data files shown in Figure A.1. Those files identified with the letter "C" are sequential files of card images (formatted). Each logical record in these files corresponds to a single card and contains a string of 80 characters. The formats associated with each card are given in Part 2.

Those files identified with the letter "M" are sequential files of matrix data (binary, unformatted). The structure of these files corresponds to that of FORMAT matrix data (Reference 1). For purposes of continuity, a description of this file structure is repeated here.

Each logical record in these files is of the form

ICØL, KØDE, NUM, (A(I),I=1,NUM)

where ICØL is an integer identifier for the record, KØDE is an integer flag indicating compressed or expanded mode for the data part of record (array A), NUM is an integer number equal to the number of words remaining in the record, and A is an array of variable length containing the actual data to be read or written.

The logical records in the file are structured as follows

Tape header
Matrix A header
Column 1 of matrix A
Column 2 of matrix A
⋮
Last column of matrix A
Matrix A trailer
Matrix B header
Column 1 of matrix B
Column 2 of matrix B
⋮
Last column of matrix B
Matrix B trailer
⋮
Tape trailer

The contents of the header and trailer records are as follows

	ICØL	KØDE	NUM	Data
Tape header	-10	0	7	(TNAME(I),I=1,6),TMØD
Tape trailer	-20	0	1	0
Matrix header	- 1	0	9	(MNAME(I),I=1,6),MMØD,IMAX,JMAX
Matrix trailer	- 2	0	1	0

where TNAME and MNAME are six character tape and matrix names stored one character per word with blank word fill in trailing words as necessary, TMØD and MMØD are integer numbers used as modifiers of the tape and matrix names for identification, and IMAX and JMAX are the row and column dimensions of the matrix.

In matrix column data, ICØL is a positive integer equal to the column number. If a column of a matrix has more than 50% non-zero elements, the

column is written in expanded form (KØDE=0) and NUM is equal to IMAX. If a column has less than 50% non-zero elements, the column is written in compressed form (KØDE=1). Compression is accomplished by forming an array of the non-zero values and their corresponding row locations in the column as the data part of the record. For example, if the 12th column of a matrix with a row dimension of 100 had only 3 non-zero elements, it would be compressed and appear as a logical record of the form

ICØL	KØDE	NUM	Data
12	1	6	$V_1, L_1, V_2, L_2, V_3, L_3$

where ICØL = 12 is the column number, KØDE = 1 indicates a data record in compressed form, NUM = 6 is the number of words remaining in the record (three pairs of value and location), the element values are V_1, V_2, V_3, and the row locations of these elements are L_1, L_2, and L_3. Note that L_1, L_2, L_3 must be in ascending order.

If a column of a matrix is completely null, no record for that column will be present in the file.

<u>File Contents</u>

The files shown in Figure A.1 are the master files used by the IMPACT system to pass data between each of the stand alone programs. The content of each of the card image files is given in detail in Part 2. The content of each of the matrix data files is given in Table A.1. The FORMAT tape and matrix names shown in parentheses are specified by user input and, consequently, may vary while all other names are fixed since they are imbedded in the program code.

USE OF UPDATE

The design of the IMPACT system provides for the optional use of the CDC utility UPDATE during the preprocessing phase. This phase includes the execution of the Laminate Generator, Initial Generator, and Loads Generator. Figure A.2 shows the intended use of UPDATE in an application

TABLE A.1. CONTENT OF MASTER MATRIX DATA FILES

FILE ID	FORMAT NAMES AND MODIFIERS		DESCRIPTION
	TAPE	MATRIX	
M1	MTAPE,1	UZERØ,1	U_o, original joint coordinates
		MPT,1	MPT, material property data
		ECT,1	ECT, element constants
		PRUPT,1	P_{RUPT}, reordering transform for degrees of freedom
		PRUF,1	P_{RUF}, reordering transform for elements
		KEL,1	k, lumped element stiffness
		MEL,1	m, lumped element mass
		KBEL,1	$\bar{k}$, unlumped element stiffness
		CBEL,1	$\bar{c}$, unlumped element damping
		FFBAR,1	$F_{\bar{F}}$, element force transform
		SIGFB,1	$\sigma_{\bar{F}}$, element stress transform
		EPSIG,1	ϵ_{σ}, element strain transform
		DEBT,1	$\delta\bar{e}_T$, element thermal deformations
		EVT,1	EVT, element variables
		CØNST,1	CØNST, problem constants
M2	LTAPE,1	DPØT,1	$\delta P_{(\phi)T}$, incremental applied loads

TABLE A.1. CONTENT OF MASTER MATRIX DATA FILES (Continued)

FILE ID	FORMAT NAMES AND MODIFIERS: TAPE	FORMAT NAMES AND MODIFIERS: MATRIX	DESCRIPTION
M3	(FILE20,1)	(PBUF,1)	$\bar{P}_{UF}$, element force modal transformation
		MPT,1	Copied from file M1
		UZERØ,1	
		ECT,1	
		MEL,1	
		KBEL,1	
		CBEL,1	
		FFBAR,1	
		SIGFB,1	
		EPSIG,1	
		DEBT,1	
		EVT,1	
		CONST,1	
M4	(FILE21,1)	(PBPHI,1)	$\delta\bar{P}_{(\phi)U}$, transformed incremental applied loads
		(PBUPTJ,1)	$\bar{P}_{UPTJ}$, degree of freedom modal transformation

TABLE A.1. CONTENT OF MASTER MATRIX DATA FILES (Continued)

FILE ID	FORMAT NAMES AND MODIFIERS		DESCRIPTION
	TAPE	MATRIX	
M5		CØNST,1	CØNST, augmented problem constants
		TIME,1	t, incremental time history
	WINDØW,52877 (linear)	UZERØ,1	Copied from file M3
		(PBPHI,1)	Copied from file M4
		(PBUPTJ,1)	Copied from file M4
	TAPE,1 (non-linear)	RESPNS,β	$\bar{\Delta}_\beta$, $\delta\bar{\Delta}_\beta$, $\bar{v}_\beta$, and $\dot{\bar{v}}_\beta$, modal response
		BARS,β	$\bar{F}_{K_{\beta B}}$, σ_{β_B}, and ϵ_{β_B}, bar element forces, stresses, and strains
		MEMBRN,β	$\bar{F}_{K_{\beta_M}}$, σ_{β_M}, and ϵ_{β_M}, membrane element forces, stresses, and strains
		CELLS,β	$\bar{F}_{K_{\beta C}}$, σ_{β_C}, and ϵ_{β_C}, cell element forces, stresses, and strains where β is the increment number and these four matrices are repeated for each time increment. If there are no elements of a given type, the corresponding matrix will not be present.

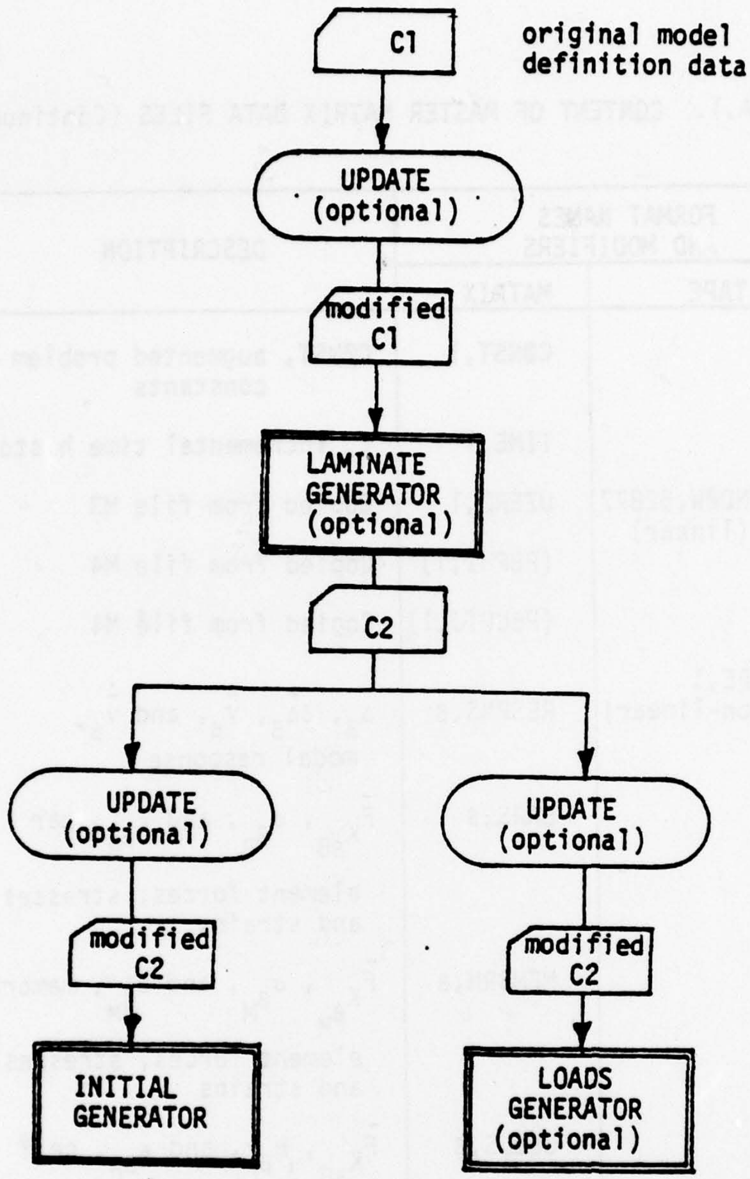


Figure A.2. Function of UPDATE in Preprocessing

using all three preprocessing programs. The basic function of UPDATE in the IMPACT system is to edit the model definition data as necessary for each of the preprocessing programs. A secondary function is to permanently store the model definition data in an easily accessible form once it has been read into the system. On a large model with a large amount of data, this will avoid many card handling and reader errors each time the model definition data is required.

In Figure A.2, each of UPDATE steps as well as the execution of the Laminate and Loads Generators are optional. Obviously, many combinations of these programs are possible in applying these tools to the variety of design problems a user might encounter. Suffice to say that the effective use of UPDATE in the preprocessing phase will enhance the users effectiveness by alleviating card handling problems.

SECTION III
OPERATIONAL CONSIDERATIONS

GENERAL

Only one of the six new programs in the IMPACT system currently uses the overlay capability of the CDC operating system. This feature is used extensively by the Initial Generator. The overlay is accomplished using the SEGLOAD option of the loader. The SEGLOAD directives for implementation of this program are given in Section V under the heading CORE UTILIZATION.

Significant savings in core requirements could be realized by using overlay in the implementation of the Linear and Non-Linear Incremental Solution programs. The remaining new programs coded for IMPACT are relatively small and would not yield enough savings to justify overlay. The FORMAT program already uses this feature.

The following tables gives 1) minimum core requirements for the current version of each program as implemented, and 2) the associated size of blank common in the compiled code as implemented where applicable. The core requirement is in octal and the blank common region is in decimal.

PROGRAM	CORE REQUIREMENT (octal)	BLANK COMMON LENGTH (decimal)
Laminate Generator	130000	NA
Initial Generator	130000	NA
Loads Generator	71000	NA
FORMAT Phase II	100000	10000
Linear Incremental Solution	104000	8000
Non-Linear Incremental Solution	134000	8000
Postprocessor	60000	10000

EXTENDING BLANK COMMON

The FORMAT Phase II program, the Linear and Non-Linear Incremental Solutions, and the Postprocessor use blank common exclusively for core storage of data during their execution. Space is allocated within the blank common region for all arrays required in each program. The array space is allocated according to problem size as defined by input data.

Even though the blank common regions are of fixed dimension in the source code, the effective blank common region can be increased at execution time without recompiling any code when operating on the CDC system. By requesting additional core on the job request card and supplying input data to the program indicating the increased size of blank common, larger problems can be processed than could be accommodated by the dimensioned size of the work area in the compiled code.

For example, a program requires a field length of 100000 words (octal) with a blank common region of 10000 words (decimal). For a given problem, an increase of 2000 words (decimal) is required in the blank common region. By requesting an additional 4000 words (octal) for program execution to account for the 2000 word (decimal) increase in blank common region and inputing data to the program specifying this increase in available work space, the program could process the larger problem without recompiling any code.

Of course, this procedure can be used only with a program whose structure and input are consistent with this philosophy. The four programs of the IMPACT system mentioned above conform to these requirements. The blank common size requirements and associated input data to over ride the size parameters in the code are given in Sections VII, VIII, and IX of this document under the heading LIMITATIONS. Again, input card formats associated with this data are given in Part 2. Similar information regarding FORMAT Phase II is given in References 6 and 10 and discussed in Part 2.

OVER RIDING FILE NAMES

On the CDC system when executing multiple stand alone programs as may be done using IMPACT, it may be necessary to over ride system default file names because of conflicts between two programs. That is, one program may output its data on a file named TAPE1 and the second program may expect its input on TAPE3. In order to resolve this conflict, the default file name in one of the programs must be temporarily renamed during the execution of that program.

On the CDC system, file names of FORTRAN programs are established by means of the PROGRAM statement, the first statement of the main program. The system provides for over riding these names at execution time by means of a system control card. The format of this command, however, requires foreknowledge of the sequence of appearance of file names in the PROGRAM statement for a given program.

Table A.2 gives the PROGRAM statements for each of the seven programs in the IMPACT system. It shows all files that are used by each program, and, together with Figure A.1, implicity defines all files used as scratch as well as those used for master input/output.

SYSTEM CONTROL CARDS

As previously stated, the seven programs of the IMPACT system may be used in any number of combinations in actual application to the variety of design problems that may be encountered. However, in order to show an example of a complete deck set up including system control cards and data, a single run using all components of the IMPACT system is described here.

Table A.3 gives the system control cards for a complete solution while Table A.4 lists the corresponding user input data. The complete job is broken down into steps for reference in the tables and this dis-

TABLE A.2. PROGRAM AND FILE DECLARATIONS

LAMINATE GENERATOR

```
    PRØGRAM LAMGEN ( TAPE1,TAPE2,ØUTPUT,TAPE6=ØUTPUT )
```

INITIAL GENERATOR

```
    PRØGRAM BIRDG1 ( TAPE1=512,INPUT,ØUTPUT,TAPE5=INPUT,TAPE6=ØUTPUT,
  .            TAPE7 =512, TAPE8 =512, TAPE9 =512, TAPE10=512,
  .            TAPE11=512, TAPE12=512, TAPE13=512, TAPE14=512,
  .            TAPE15=512, TAPE16=512, TAPE17=512, TAPE18=512 )
```

LOADS GENERATOR

```
    PRØGRAM LØDGEN ( TAPE1,TAPE2,TAPE3,ØUTPUT,TAPE6=ØUTPUT )
```

FORMAT

```
    PRØGRAM FØRMAT ( TAPE1=512,TAPE2=512,TAPE3=512,TAPE4=512,
   1 INPUT=512,TAPE5=INPUT,ØUTPUT=512,TAPE6=ØUTPUT,TAPE7=512,
   6 TAPE8=512,TAPE9=512,TAPE10=512,TAPE14=512,TAPE15=512,TAPE16=512 )
```

LINEAR INCREMENTAL SOLUTION

```
    PRØGRAM RESPNS(TAPE1 =512,TAPE2 =512,TAPE3 =512,TAPE4 = 512
   1,INPUT =512,TAPE5 =INPUT,ØUTPUT=512,TAPE6=ØUTPUT,TAPE7 =512
   2,TAPE8 =512,TAPE9 =512,TAPE10=512,TAPE11=512,TAPE12=512
   3,TAPE13=512,TAPE14=512,TAPE15=512,TAPE16=512,TAPE17=512,TAPE18=512
   4,TAPE19=512,TAPE20=512,TAPE21=512,TAPE22=512,TAPE23=512
   5,TAPE29=512                                                          )
```

NON-LINEAR INCREMENTAL SOLUTION

```
    PRØGRAM RESPNS(TAPE1 =512,TAPE2 =512,TAPE3 =512,TAPE4 =512
   1,INPUT =512,TAPE5 =INPUT,ØUTPUT=512,TAPE6=ØUTPUT,TAPE7 =512
   2,TAPE8 =512,TAPE9 =512,TAPE10=512,TAPE11=512,TAPE12=512
   3,TAPE13=512,TAPE14=512,TAPE15=512,TAPE16=512,TAPE17=512,TAPE18=512
   4,TAPE19=512,TAPE20=512,TAPE21=512,TAPE22=512,TAPE23=512
   5,TAPE30=512,TAPE31=512  )
```

POSTPROCESSOR

```
    PRØGRAM PØST ( TAPE1,TAPE2,TAPE3,
   1                 INPUT,TAPE5=INPUT,ØUTPUT,TAPE6=ØUTPUT )
```

TABLE A.3. SYSTEM CONTROL CARDS FOR COMPLETE SOLUTION

STEP	SYSTEM CONTROL CARDS
	RCQ,T075,IO150,CM140000,STC38. D750545,MORRIS,32096 LIMIT(7777)
1	UPDATE(N,F,C=TAPE1) RETURN(NEWPL) REWIND(TAPE1)
2	ATTACH(LGO,LAMGENLGO) MAP(ON) LGO. RETURN(TAPE1,LGO) REWIND(TAPE2)
3	UPDATE(N,F,C=CASE) RETURN(NEWPL,TAPE2) REWIND(CASE)
4	ATTACH(BSLCRD,BIRDG1SL) UPDATE(N,F) REWIND(COMPILE)
5	ATTACH(BLGO,BIRDG1LGO) MAP(ON) SEGLOAD(I=COMPILE,B=BABS) LDSET(PRESET=ZERO) LOAD(BLGO) NOGO. RETURN(BSLCRD,COMPILE,BLGO,NEWPL) REWIND(BABS) BABS(TAPE2,CASE) RETURN(BABS) REWIND(TAPE2,CASE)
6	ATTACH(LGO,LODGENLGO) MAP(ON) LGO(CASE,TX) RETURN(CASE,TX,LGO) REWIND(TAPE3)
7	ATTACH(PH2,PHASE2A,CY=1) PH2. REWIND(TAPE2,TAPE3,TAPE4)
8	PH2(,,TAPE4,TAPE3) REWIND(TAPE2,TAPE3,TAPE4)
9	PH2(,,,TAPE20,,,,,TAPE21) REWIND(TAPE20,TAPE21)
10	ATTACH(LGO,LINEARLGO) MAP(ON) RFL(140000) LGO. RETURN(LGO,TAPE20,TAPE21) REWIND(TAPE2)
11	ATTACH(LGO,POSTLGO) MAP(ON) LGO.

TABLE A.4. INPUT DATA FOR COMPLETE SOLUTION

```
STEP | INPUT DATA
     | *DECK CASE
     |  1                 75.0          9332.0
     |  1                        1.0E+6            1.0E-12
     |  19999
     |  2   1                                           1.0
     |  2   3                            4.0            1.0
     |  2   5             4.0                           1.0
     |  2   7             4.0            4.0            1.0
     |  2   9             8.0                           1.0
     |  2  11             8.0            4.0            1.0
     |  2  13             12.0                          1.0
     |  2  14             12.0
     |  2  15             12.0           4.0            1.0
     |  2  16             12.0           4.0
     |  29999
     |  3   1  16                                                    75.0
     |  39999
     |  49999
     |  5   1   1         1.0
     |  5   2   1                        1.0
     |  5   3   1                                       1.0
     |  5   4   2         1.0
     |  5   5   2                        1.0
     |  5   6   2                                       1.0
     |  5   7   3         1.0
     |  5   8   3                        1.0
     |  5   9   3                                       1.0
  1  |  5  10   4         1.0
     |  5  11   4                        1.0
     |  5  12   4                                       1.0
     |  5  13  14                                       1.0
     |  5  14  16                                       1.0
     |  59999
     |  7 100
     |  7 101 100    1    1  1.0
     |  7 199
     |  79999
     |  8   1  11 1.0
     |  89999
     |  10 100     ALUMINUM    2024-T62
     |  10 101 1  10.6    E+6
     |  10 102 1  7.44    E+6
     |  10 103 1  50000.
     |  10 104 1  66800.
     |  10 105 1  .0488
     |  10 106 1  .33
     |  10 107 1  .126    E-4
     |  10 108 1  .259    E-3
     |  10 109 1  80.
     |  10 110 1  1.0    E-03
     |  10 199
     |  109999
     |  11   1  48          .004         5000.         15.
     |  11   2   3        -.8                          -.6
     |  11   3                                         -1.0
     |  11   4            -1.0
     |  11   5              11.0         2.0           1.0
     |  11   6   1                       1.0
     |  11   6   2          4.0          1.0
     |  11   6   3          8.0          1.0
     |  119999
```

TABLE A.4. INPUT DATA FOR COMPLETE SOLUTION (Continued)

STEP	INPUT DATA
1	12 1 9 11 13 15 12 2 5 7 9 11 12 3 1 3 5 7 129999 20 1 13 14 100 1.0 20 2 15 16 100 1.0 209999 30 1 9 11 15 13 100 .5 30 2 10 12 16 14 100 .5 309999 40 1 1 3 7 3 40 2 5 7 11 9 409999 50 1 9 .4 E-2 .4 E-2 .4 E-2 50 2 11 .4 E-2 .4 E-2 .4 E-2 50 3 13 .4 E-2 .4 E-2 .4 E-2 50 4 15 .4 E-2 .4 E-2 .4 E-2 509999
3	*DECK CASE1 *READ TAPE2
4	*READ RSLCRD
7	$FORMAT STANDARD $RUN GO, LOGIC INPUT TAPE (MTAPE,1) INPUT TAPE (LTAPE,1) OUTPUT TAPE (DECOMP,1) $INSTRUCTION PT,OPT = OPOT .DEJCOL. (1) SAVE (DECOMP) OPOT MR = PRUF,MEL .SEQMF. PRUPJ,PRUPS = PRUPT .DEJCOL. (48) PR = PRUPJ .MULT. PT PRT = PR .TRANSP. X,LTL,UR = PRUF,KEL .SEQMF. PRT UT = PRUPT .TMULT. UR SAVE (DECOMP) MR,PRUPJ,LTL,UR PRINT (,,,) UT $END
8	$FORMAT STANDARD $RUN GO, LOGIC INPUT TAPE (MTAPE,1) INPUT TAPE (DECOMP,1) OUTPUT TAPE (TRANSF,1) $INSTRUCTION VAL,TR = MR .USER06. LTL PRINT (,,,) VAL PBUPJ = TR .TMULT. PRUPJ PBUF = TR .TMULT. PRUF DPRO = PBUPJ .MULT. DPOT SAVE (TRANSF) TR,PBUPJ,PBUF,DPBO MODES = PRUPJ .TMULT. TR PRINT (,,F2,,05) MODES $SPECIAL 25 25 1.0E-6 $END

TABLE A.4. INPUT DATA FOR COMPLETE SOLUTION (Continued)

STEP	INPUT DATA
9	`$FORMAT           STANDARD`
	`$RUN              GO, LOGIC`
	`     INPUT TAPE (MTAPE,1)`
	`     INPUT TAPE (TRANSF,1)`
	`     OUTPUT TAPE (FILE20,1)`
	`     OUTPUT TAPE (FILE21,1)`
	`$INSTRUCTION`
	`     SAVE (FILE20) PRUF`
	`     SAVE (FILE20) MPT`
	`     SAVE (FILE20) UZERO`
	`     SAVE (FILE20) ECT,MEL,KBEL,CBEL,FFBAR`
	`     SAVE (FILE20) SIGFB,EPSIG,DEBT,EVT,CONST`
	`     SAVE (FILE21) DPBO`
	`     SAVE (FILE21) PRUPJ`
	`$END`
10	`    1    6    10    25F    16 15000`
	`   10.0        20.0         30.0        40.0        50.0        60.0`
	`   70.0        80.0         90.0       100.0`
11	`1        11`
	`2        1111`
	`3        111`
	`4        1111`
	`5        1111`
	`6        1111`
	`7                  CARD 1, FIRST TITLE LINE`
	`8                  CARD 2, FIRST TITLE LINE`
	`9                  CARD 1, SECOND TITLE LINE`
	`10                 CARD 2, SECOND TITLZ LINE`
	`20    9999    1=  10`
	`30    9999    1=  16`

cussion. The following files are assumed to be permanently stored disc files in the system.

LAMGENLGØ	Laminate Generator relocatable decks
BIRDG1SL	Initial Generator SEGLØAD directives preceded by a *DECK UPDATE control card (card images)
BIRDG1LGØ	Initial Generator relocatable decks
LØDGENLGØ	Load Generator relocatable decks
PHASE2A, CY=1	FØRMAT Phase II absolute file
LINEARLGØ	Linear Incremental Solution relocatable decks
PØSTLGØ	Postprocessor relocatable decks

During this discussion, Figure A.1 should be referred to for master input/output files of each program. Also, Table A.2 should be referred to for the sequence of appearance of file names in the PRØGRAM declarations of each program. It is assumed that the reader has a working knowledge of the CDC system and its control cards.

In Table A.3, the job card requests 140000 words of central memory for the run which is more than sufficient to load and execute all programs. The LIMIT card requests more than the system default disc storage space normally allocated to a job.

The CDC utility UPDATE is executed first (Step 1) receiving input from the system input file and outputing the CØMPILE file under the name TAPE1. In Step 2, the Laminate Generator uses all default file names accepting file TAPE1 as input and creating file TAPE2 as output. TAPE1 is the partial model definition data and TAPE2 is the augmented model definition data. This is followed by another execution of UPDATE (Step 3) simulating a final editing and/or save of this data which, rather than being output under the default file name CØMPILE, is renamed CASE.

Step 4 executes UPDATE again to create a card image input stream for SEGLØD which is output under the default name CØMPILE.

Step 5 includes both the loading of the Initial Generator and its execution. Input directives to SEGLØAD is the card image CØMPILE file from Step 4. Input to the Initial Generator is the complete model definition data, card image file CASE. The normal output file TAPE1 is over ridden and renamed TAPE2.

Next the Load Generator is executed (Step 6). The normal input file TAPE1 is renamed CASE in order to accept the same model definition data used by the Initial Generator. The output is on TAPE3, the default file name for the binary matrix data output file. However, the normal card image output file TAPE2 is renamed to the dummy name TX since TAPE2 is already in use as the Initial Generator output file.

The following three steps, 7, 8, and 9, execute the FØRMAT Phase II program to assemble the input files necessary for the Linear Incremental Solution which follows. In the first execution, all default file names are used. Input is on file TAPE2 from Step 5 and TAPE3 from Step 6. Output is on TAPE4. In the second execution (Step 8), input consists of file TAPE2, the same file input to Step 7, and TAPE4 output from Step 7. In this step, therefore, the normal input file name TAPE3 is over ridden and renamed TAPE4, and the normal output file name TAPE4 is over ridden and renamed TAPE3. This sets up the stage for the final execution (Step 9) in which the input is, again, file TAPE2 from Step 5, and file TAPE3 output from Step 8. The normal output file names, TAPE4 and TAPE7, are renamed TAPE20 and TAPE21 for compatibility with the following step.

The Linear Incremental Solution is then executed (Step 10) using all default file names. Output is on TAPE2. In this step, blank common is extended to accommodate the size of the problem. On the first input card for this step (Table 3.3, Step 10), the available blank common is specified to the program in decimal as 15000 (last value on card). This is 7000 words (decimal) greater than the size of blank common in the compiled code. Therefore, in order to make additional core available for

execution, an RFL command is placed before the load and go command, LGØ. This effectively over rides the field length the loader normally establishes from the relocatable file it accesses for the load. The requested field length on the RFL card, 140000 words (octal), is sufficient to compensate for the 7000 words (decimal) added to blank common. (See minimum core requirements and dimensioned blank common block sizes discussed at the beginning of this section).

The last step, execution of the Postprocessor (Step 11) is then performed using all default file names, in which case, TAPE2 is the input file.

This example would be identical if the Non-Linear Incremental Solution had been used rather than the linear with the following exception. The default output file for the non-linear is TAPE23. The last control card, the command executing the Postprocessor, would, therefore, have to over ride the default input file name of TAPE2 to TAPE23 and would appear as

LGØ (, TAPE23)

SECTION VI

REFERENCES

1. Pickard, J., "FORMAT-Fortran Matrix Abstraction Technique, Volume V, Engineering User and Technical Report", AFFDL-TR-66-207, Volume V, October 1968; Volume V Supplement I, June 1970; Volume V Supplement II, April 1973; Volume V Supplement III, December 1977.

2. Barber, J. P., Wilbeck, J. S. and Taylor, H. R., "Bird Impact Forces and Pressures on Rigid and Compliant Targets", University of Dayton Research Institute Report UDRI-TR-77-17, March 1977.

3. Greene, F. E., "Testing for Mechanical Properties of Monolithic and Laminated Polycarbonate Materials", Volume I, Technical Report AFFDL-TR-77-96, October 1977.

4. Rhodes, G. F. and Denke, P. H., "Damping, Static, Dynamic, and Impact Characteristics of Laminated Beams Typical of Windshield Construction", Technical Report AFFDL-TR-76-156, September 1977.